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FEDERAL WATER QUALITY ADMINISTRATION

# DOCUMENTATION REPORT
# FWQA DYNAMIC ESTUARY MODEL

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The report documents the theory, development, verification, and application of a mathematical model which predicts the hydrodynamic and water quality behavior of well-mixed tidal rivers and estuaries. The two-dimensional hydrodynamic behavior is predicted by solving by finite difference methods the one-dimensional forms of the equations of motion and continuity applied to a two-dimensional non-uniform grid network which characterizes the prototype. This same network is utilized as the basis for predicting simultaneously the distributions of up to five conservative or non-conservative water quality constituents utilizing advective and diffusive transport mechanisms. The results of model verification and sensitivity studies are presented as well as complete documentation, including program listings, flow diagrams, input and output formats, and sample output.

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# DOCUMENTATION REPORT

# FWQA DYNAMIC ESTUARY MODEL

by

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# PREFACE

The purpose of this document is to present the necessary theory, background, and guidelines for applying the FWQA dynamic estuary model to an arbitrary estuary. The discussion reflects FWQA experience in applying the model to the San Francisco and San Diego Bay estuaries. The model has been utilized to simulate a wide variety of hydraulic and water quality conditions in these two systems, and has, through the course of its development, testing, and use, undergone significant change. New features continue to be incorporated as the model is utilized and applied to new systems and to new problems. It is anticipated that supplemental reports describing new applications and new model features will be prepared when warranted.

The preparation, review, and publication of this documentation report has largely been a joint and cooperative effort between the California-Nevada Basins Office (Alameda, California) of the FWQA Southwest Region and the Systems Analysis and Economics Branch of the FWQA Headquarters Office. Water Resources Engineers, Inc. of Walnut Creek, California who, under contract, developed the model, has continued to develop new model features and has provided insight and guidance on the use of the model over the past several years.

It was primarily through the efforts and foresight of James C. McCarty, current Deputy Director of the Southwest Region, who served as project officer for the development contracts, that the model was carried to a successful completion. Dr. Howard S. Harris, California-Nevada Basins Office, also provided valuable insight and suggestions during all phases of the development, testing, and use of the model and has contributed significantly to the writing and editing of this document.

The principal author of this report is Kenneth D. Feigner, currently on the FWQA headquarters staff, who was responsible for implementing the model studies during assignment to the FWQA Central Pacific Basins Office in Alameda.

Other contributors to this report from the FWQA Alameda Office include David R. Minard, who conducted the prototype tracer studies for model verification and contributed to the writing of this report, William M. Thurston, who contributed to the writing of the user's manual, Marie Cleveland who prepared the figures, and Karen S. Relephord who typed preliminary drafts of the report.

Additional contributions from FWQA headquarters staff include the adaptation of the model components to the IBM 360 System by William S. Gillam III and the typing of the intermediate and final drafts of this report by Mrs. Ida Weiner.

The preliminary draft of this report was distributed to selected FWQA employees for review and comment. Constructive comments and suggestions were received from Mr. R. J. Callaway of the National Coastal Pollution Research Program at the Pacific Northwest Water Laboratory in Corvallis, Oregon, from Messrs. J. J. Troyan and David R. Minard of the California-Nevada Basins Office in Alameda, California, from Dr. Norbert A. Jaworski and Mr. Leo J. Clark of the Chesapeake Technical Support Laboratory in Annapolis, Maryland, from Mr. Edwin L. Johnson, Chief of the Systems Analysis and Economics Branch, FWQA, Headquarters, and Mr. William P. Somers of the Systems Analysis and Economics Branch, FWQA, Headquarters.

Each suggestion was considered and, where possible, was incorporated into this final version of the report. The authors are grateful for all comments received and for the resulting improved document.

Kenneth D. Feigner
Howard S. Harris, Ph.D.
July 1970

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## PART I. THEORY AND APPLICATION

### INTRODUCTION

The dynamic estuary model described herein was originally developed by Water Resources Engineers, Inc., of Walnut Creek, California, under contract to the Division of Water Supply and Pollution Control of the Public Health Service [1]. Additional development for the Federal Water Pollution Control Administration (FWPCA) [2] and for the State of California [3] was also completed by that firm. Development and refinements have also been completed by the Federal Water Quality Administration (FWQA) for utilization in specific studies [4,5]. Limited comparisons between model and prototype behavior have been presented in the previously cited references and elsewhere [6,7].

Although the model was developed specifically for the San Francisco Bay-Delta estuary, experience by Water Resources Engineers and FWQA has demonstrated its applicability to other estuaries. The model represents the two-dimensional flow and dispersion characteristics of an estuary and can be applied to any estuary wherein vertical stratification is either absent or is limited to relatively small areas within the estuary. This would include estuaries such as San Francisco Bay in which stratification is limited to the area near the mouth or to other areas only during specific periods of the year such as during peak freshwater outflow. If appropriate boundary conditions can be specified the model can be applied to particular problem areas without modeling the entire estuary. However the problems associated with specifying appropriate boundary conditions under such applications can be formidable, and to avoid such problems it may be necessary to extend the modeled area to boundaries with relatively constant (or at least predictable) flow and quality characteristics.

The model can accommodate a range of time and space scales as may best suit the nature of the problems and the physical characteristics of a particular estuary. In applications described herein predictions for tidal flow and stage were computed at frequencies on the order of 1/2 to 5 minutes on the time scale and at intervals on the order of a few hundred to several thousand feet on the space scale. Predictions of quality levels are computed on the same space scale as for the hydraulic parameters but on an expanded time scale of the order of 15 minutes to one hour. The model is thus truly dynamic in character; it predicts fluctuating tidal flows and computes tidally varying concentrations of constituents, in contrast to a non-tidal model based on the net flow through the estuary such as that developed for the Delaware Estuary [8].

The model can accommodate both conservative and non-conservative constituents including the interrelationship between biochemical oxygen demand (BOD) and dissolved oxygen (DO).

The model consists of two separate, but compatible components; namely, a hydraulic program (DYNHYD), and a quality program (DYNQUA). A third program, a harmonic regression analysis (REGAN) is utilized to reduce the input requirements for specifying the tidal conditions imposed on the system. A hydraulic extract program (HYDEX) in the form of a subroutine of the hydraulic program, summarizes the hydraulic output and prepares the appropriate hydraulic input to the quality program. Similarly a quality extract program (OUALEX) is incorporated as a subroutine of the quality program to summarize the output from the quality program. A final program (DATAP) has been developed to prepare many of the basic data inputs to the hydraulic program.

## HYDRAULIC MODEL THEORY

The hydraulic behavior of estuaries and other coastal waters is usually influenced significantly by the ocean tides, by the freshwater inflow to the system, and by the shape of the estuary and inflowing river system. While Coriolis and wind forces may be significant in certain estuaries they are not represented in the model described herein. In modeling the hydraulic behavior of an estuary the problem is essentially one of solving the equations describing the propagation of a long wave through a shallow water system. In open channels in which the flow is predominately one-dimensional the hydraulic behavior can be described by the one-dimensional form of the equations of motion and continuity [9]. The equation of motion takes the form:

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - K|u|u - g\frac{\partial H}{\partial x} \qquad (1)$$

where:

u = velocity along x-axis, positive in the direction of increasing x
x = distance along x-axis
H = water surface elevation
g = acceleration of gravity
K = frictional resistance coefficient
t = time

The equation of continuity can be expressed as:

$$\frac{\partial H}{\partial t} = -\frac{1}{b}\frac{\partial(u\,A)}{\partial x} \qquad (2)$$

where:

b = mean channel width
A = cross sectional area of the channel

The assumptions on which equations (1) and (2) are based include:

1. Acceleration normal to the x-axis is negligible
2. Coriolis and wind forces are negligible
3. The channel is straight
4. The channel cross-section is uniform throughout its length
5. The wave length is at least twice the channel depth
6. The bottom of the channel is level

The term on the left hand side of the equation (1) is the local acceleration (time rate of change of velocity). The terms on the right side of the equality sign represent, respectively, the rate of momentum change by mass transfer, the frictional resistance, and the gravitational driving force or potential difference between the ends of the channel element. The absolute value sign in the frictional resistance term assures that the resistance always opposes the direction of flow.

The left hand side of equation (2) is the time rate of change of the water surface elevation while the right hand side represents the change in storage over the channel length per unit width of channel.

As presented, equations (1) and (2) both apply to a channel. For a system represented by a network of channels these equations could be solved for each channel in the network and boundary conditions matched at the connecting junctions. To minimize computational requirements, the elevation of the fluctuating water surface (and the corresponding change in volume) of the system is associated with the junctions while flow (velocity and discharge) is associated with the channel elements of the network. This approach permits the application of equation (1) to the channel elements and equation (2) to the junctions of the network.

In finite difference form, the equation of motion becomes:

$$\frac{\Delta U_i}{\Delta t} = -U_i \frac{\Delta U_i}{x_i} - K|U_i|\,U_i - g\frac{\Delta H}{x_i} \qquad (3)$$

where i refers to the channel under consideration, U is the mean velocity, and x is the channel length.

Similarly the equation of continutiy becomes:

$$\frac{\Delta H_n}{\Delta t} = \frac{\Sigma Q_n}{A^*_n} \tag{4}$$

where the subscript n denotes the junction under consideration. The term $\Sigma Q_n$ is the algebraic flow rate into the junction, both from the channels entering the junction and from external sources (waste discharges, inflows, diversions, etc.). The term $A^*_n$ is the surface area of the junction.

The roughness coefficient K in equation (3) can be evaluated by Manning's equation, which can be written as:

$$\frac{dH}{dx} = \frac{n^2 U^2}{2.208\ R^{4/3}} \tag{5}$$

where:

$\frac{dH}{dx}$ = Energy gradient

n = Manning's roughness coefficient
U = mean velocity in channel
R = hydraulic radius

Application of Manning's equation is normally restricted to conditions of steady uniform flow. For a tidally influenced estuary, few, if any, of the channels experience steady flow. However, over relatively short time intervals the flow can be considered steady. In fact steady, uniform flow is implicit in the assumptions listed previously for application of equations (3) and (4).

The relationship between frictional resistance and the slope of the energy gradeline can be expressed as:

$$K|U|U = g\frac{dH}{dx} \tag{6}$$

Substituting equation (5) into (6) results in the definition of K:

$$K = \frac{g\ n^2}{2.208\ R^{4/3}} \tag{7}$$

The determination of the velocity gradient term, $\Delta U_i/x_i$, in equation (3) presents certain computational difficulties in that the computed velocity in each channel element is constant for the entire length of the channel, hence there is no velocity gradient predicted within a given channel. Although a velocity gradient could be established by utilizing the predicted velocities in the next adjacent upstream and downstream channel elements, such a technique is not completely appropriate in that in networks with branching channels there may be several "upstream" and "downstream" channels, each with a different orientation.

To avoid this difficulty $\Delta U_i/x_i$ in equation (3) is computed by utilizing the continuity equation (2) as suggested by Lai [10]. From equation (2):

$$\frac{b\partial H}{\partial t} = -\frac{u\partial A}{\partial x} - A\frac{\partial u}{\partial x} \tag{8}$$

or

$$-\frac{\partial u}{\partial x} = \frac{b}{A}\frac{\partial H}{\partial t} + \frac{u}{A}\frac{\partial A}{\partial x} \tag{9}$$

In finite difference form equation (9) becomes:

$$-\frac{\Delta U_i}{x_i} = \frac{b_i}{A_i}\frac{\Delta H_i}{\Delta t} + \frac{U_i}{A_i}\frac{\Delta A_i}{x_i} \tag{10}$$

Even in this form $\Delta U_i/x_i$ is not tractable in that equation (1) applies to a channel element and the two terms $\Delta H/\Delta t$ and $\Delta A_i/x_i$ in equation (10) are not computed for channels. Since fluctuations in water surface elevation are associated with junctions $\Delta H_i$ in equation (10) is computed as the average of the changes in elevation during the time step at the junctions at both ends of the channel. Similarly the cross-sectional area gradient $\Delta A_i/x_i$ is obtained by computing an area at both ends of the channel based on the predicted water surface elevations at those junctions.

The numerical integration of equations (3) and (4) was programmed for solution using a modified Runge-Kutta procedure. Equation (3) is first solved for each channel in the network with a time interval equal to one-half the full time interval $\Delta t$. Similarly Equation (4) is solved for each junction for the half-time interval. These half-step results (velocities, flows, areas, and heads) then serve as the basis for solving the equations using the full time interval. A step by step solution of equations (3) and (4) proceeds as follows:

(1) The mean velocity for each channel is predicted for the middle of the next time interval using the values of channel velocities and cross-sectional areas and the junction heads at the beginning of the time interval.

(2) The flow in each channel at the middle of the next time interval is computed based on the above velocity and the cross-sectional area at the beginning of the interval.

(3) The head at each junction at the middle of the next time interval is predicted based on the above predicted flows.

(4) The cross-sectional area of each channel is adjusted to the middle of the next time interval based on the above predicted heads.

(5) The mean velocity for each channel is predicted for the end of the next time interval using the values of channel velocities and cross-sectional areas and junction heads at the middle of the interval.

(6) Steps (2), (3) and (4) are repeated for the end of the time interval. Computation proceeds through a specified number of $\Delta t$ time intervals.

The solution will converge, for a given set of boundary conditions, to a dynamic equilibrium condition wherein the velocities and flows in each channel and the heads at each junction repeat themselves at intervals equal to the period of the tide imposed at the seaward boundary of the system.

Selection of the time interval $\Delta t$ to be used in the program is based primarily on a computational stability criterion. Generally, the solution will be stable if the following relationship between the time interval $\Delta t$, the channel length $x_i$, the tidal velocity $U_i$, and the celerity of a shallow water wave, $\alpha$, is maintained.

$$x_i \geq (\alpha_i \pm U_i)\Delta t \tag{11}$$

The celerity of a shallow water wave, $\alpha$, for a given channel can be roughly determined from the relationship:

$$\alpha_i = \sqrt{gy} \tag{12}$$

where $g$ = acceleration of gravity
$y$ = maximum mean channel depth

Ideally $x$ and $\Delta t$ should be made as large as possible, consistent with the degree of detail and precision required in the solution. For many of the channels of the San Francisco Bay Delta the maximum channel length was fixed, i.e., $x$ could not exceed the actual length of the channel. Thus, in a sense, the shortest channel modeled dictates the maximum time interval which can be used. However, it is apparent from equation (12) that a relationship such as equation (11) cannot be considered precise in that the wave celerity $\alpha$ varies with the depth of the water, which of course, fluctuates with the tide. Even if, for a given tidal condition, the maximum wave celerity is used in the relationship there is no assurance that for some other tidal condition (or higher inflow condition) the same maximum mean channel depth would result. The same is true of the maximum mean tidal velocity U. The maximum mean tidal velocity is dependent on the imposed tidal condition and on the freshwater inflow to the system. There is the additional problem of even estimating the maximum mean tidal velocity in a channel. In the absence of adequate field measurements of channel velocities for each and every channel in the network the best that can be done is an estimate based on "typical" channel velocities in the system. In spite of these difficulties, however, equation 11 does serve as a very useful guide for selecting the time interval and the lengths of the channel elements in the network.

## HYDRAULIC MODEL APPLICATION

The mathematical model, as described herein was developed originally for and limited to the system of interconnected channels of the Sacramento-San Joaquin Delta [1]. It was later determined that the one dimensional equations of flow and continuity used to simulate the hydraulic characteristics of these channels could also be successfully applied to wide, shallow embayments such as Suisun, San Pablo, and San Francisco Bays [2]. While this discussion is intended as a guide for applying the dynamic estuary model to any well-mixed estuary it will be expedient to illustrate certain points in the discussion with experience gained with the San Francisco Bay system.

The San Francisco Bay system represents extremes in physical configuration and hydraulic environment, i.e., the wide, shallow embayments of San Francisco, San Pablo, and Suisun Bays and the well defined system of relatively narrow interconnected channels of the Delta. The system is illustrated in Figure 1. The entire system is tidally influenced as evidenced by the periodic fluctuation of water surface elevation at essentially every point in the system. During periods of low freshwater inflow to the Delta the hydraulic behavior of the entire system is largely tidal in nature, i.e., significant fluctuations of water surface elevations and flow reversal in channels between flood and ebb tides. During periods of high freshwater inflow to the Delta the tidal effect is less pronounced near where major rivers enter the Delta.

While the model has not been applied by FWQA to this complex hydraulic regime in its entirety it has been applied to the system beginning at the seaward entrance to San Pablo Bay (near Point Orient) and including essentially all upstream waters which are subject to tidal action. The network for this system totals some 830 junctions and 1050 channels.

### Network Configuration and Size

There is a great deal of flexibility allowed in laying out the network of interconnected channels and junctions to represent a particular system. The choice of the boundary locations should include

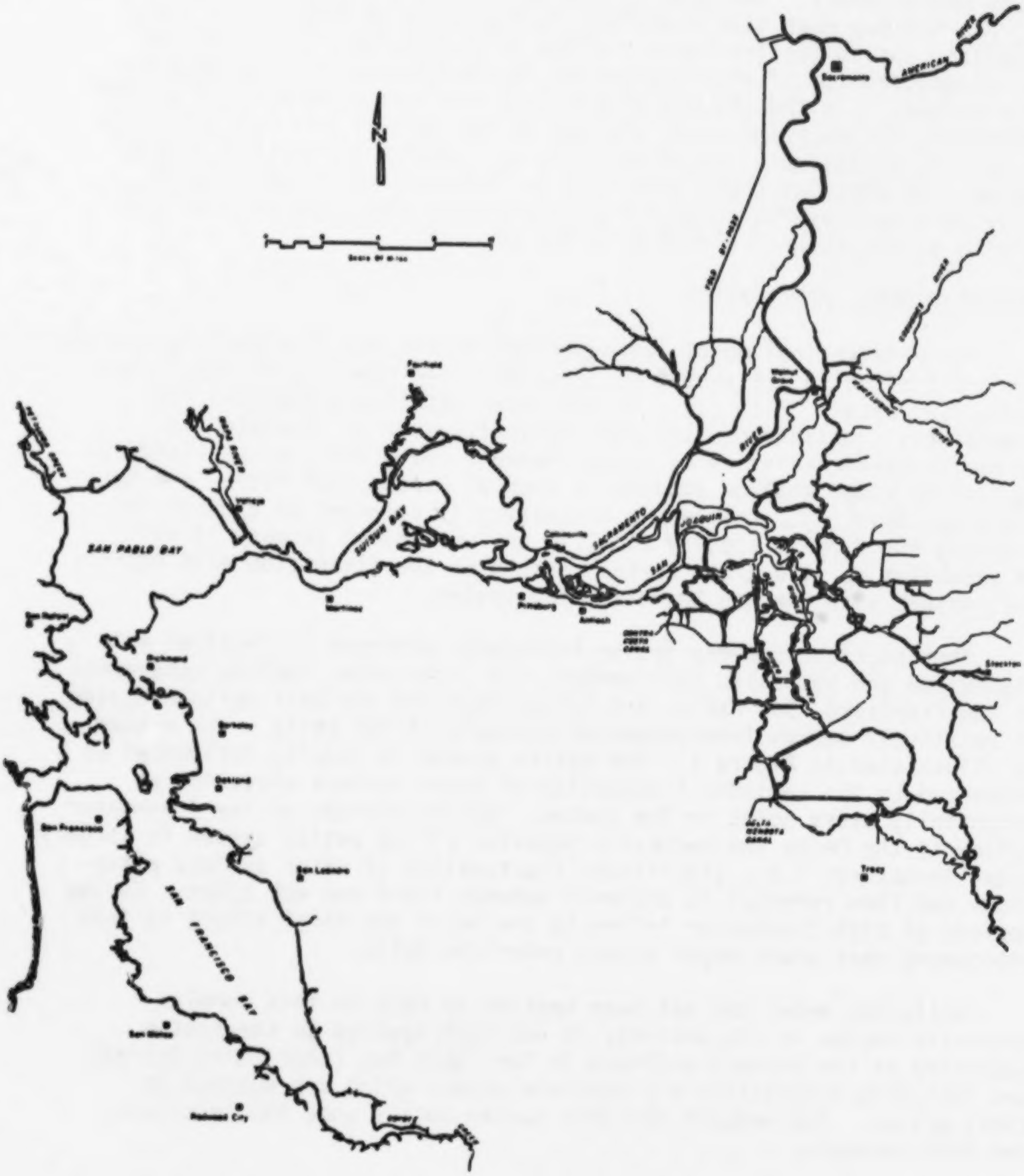


FIGURE 1. SAN FRANCISCO BAY AND DELTA

considerations of both hydraulic and quality factors. To minimize difficulties with boundary conditions the network should ideally extend to the ocean at the downstream boundary and to or beyond the limits of tidal effects on inflowing streams so that the inflow can be considered steady. Such a network eliminates problems associated with dynamic boundary conditions such as changing salinity or other quality conditions which could be present if an inland point is chosen for the seaward boundary. Other considerations which could influence the location of the network boundaries, the overall size, and the scale of network elements include the location of specific points where quality predictions are required, the location of existing or planned sampling stations and the availability of data for verification, the degree of network detail desired, and the computer time required for solution. If the model will be utilized to study the impact of anticipated physical changes in an estuary, e.g., the construction of a jetty, a salt water barrier, a ship channel, etc., the network should be laid out so that it can easily accommodate these changes. The network should initially be representative of existing conditions in order to demonstrate the model's capability to reproduce prototype behavior.

Channel elements are normally oriented in directions which minimize the variation in depth between junctions. This generally implies that the network elements which represent the dredged or naturally scoured deep-water channels of a bay are oriented parallel to these main channels of flow. For the wide, shallow portions of a bay where the principal direction of the flow is not well defined by channelization, the network can be laid out in a grid pattern with the orientation of any particular channel element being relatively unimportant. For application to Suisun and San Pablo Bays the shallow areas were characterized by a rectangular grid network.

For a system of well defined channels, such as in the Delta, the model network essentially follows the prototype configuration, i.e., if a significant channel exists in the prototype it is represented by a channel element or series of elements in the model network. Because the desired network scale may dictate channel element lengths, a prototype channel may have to be divided into a series of channel elements in the model network. The channels of the network are connected by nodes or "junctions". These network junctions thus not only exist for all real junctions in the prototype but also must connect all channel elements in the network. Figure 2 illustrates the network used for Suisun Bay and depicts the channel element orientation following the main tidal flow through Carquinez Strait and along the southern shoreline, the rectangular grid network of the embayments, and the well defined channels of Suisun and Montezuma Sloughs. The network extends to or slightly beyond the mean lower low water line (MLLW).

## Channel Parameters

The parameters associated with the channels of the network are length, width, cross-sectional area, frictional resistance coefficient

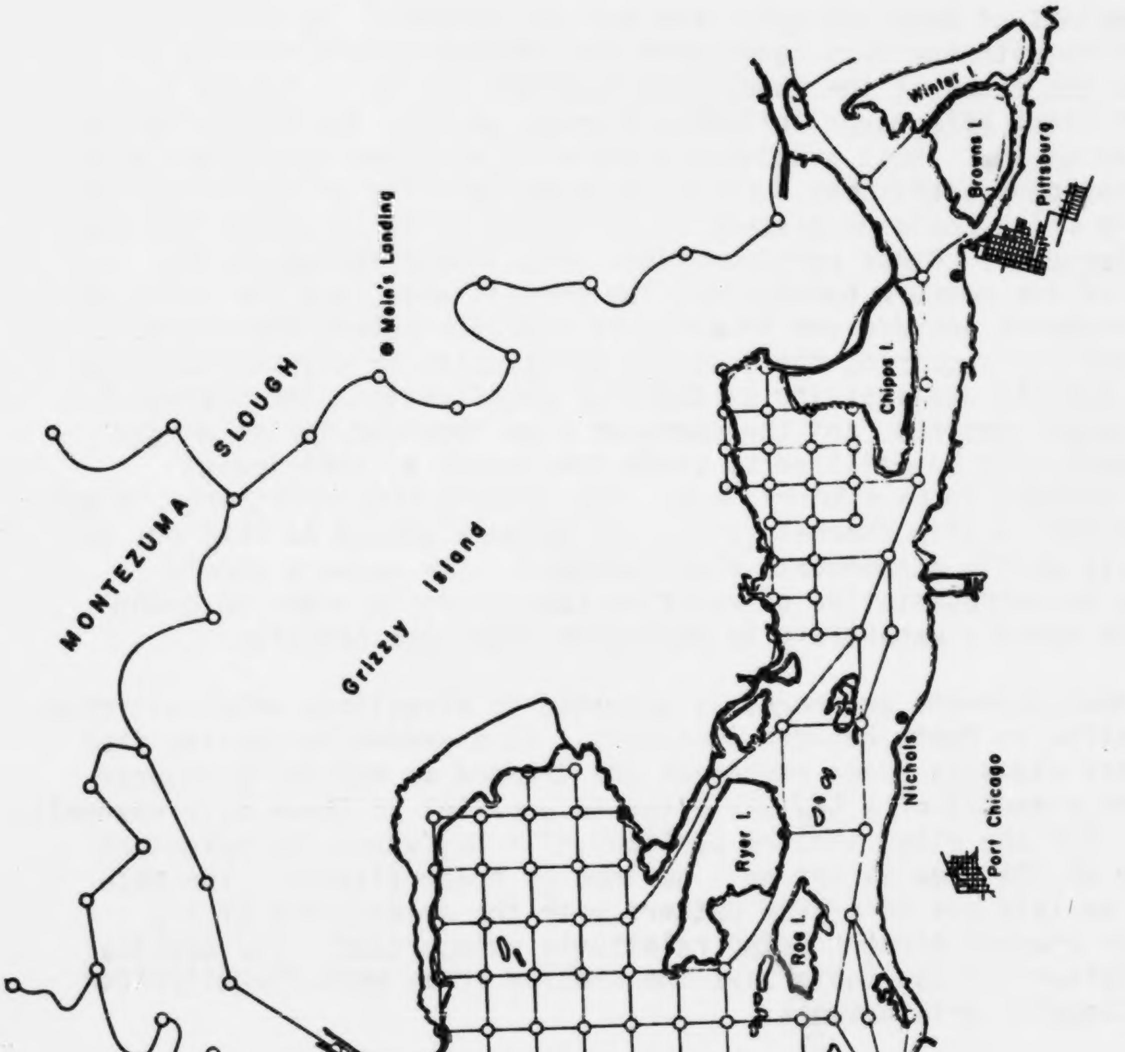


FIGURE 2. SUISUN BAY NETWORK

(Manning's "n"), velocity (or flow rate) and hydraulic radius. The network channel lengths (distance between junctions) are governed by the computational stability criteria discussed previously and by the actual length between real junctions in the prototype. Typical channel lengths in the Delta vary between 3000 feet and 5000 feet while in the Bays from 3000 feet to 7000 feet.

There is no apparent restriction on the width of the network channels although common sense would dictate that the width of a channel not be so wide that the mean velocity prediction for the channel would mask important velocity patterns. For example, for wide channels with one portion much deeper than the other, the channel might best be broken into two parallel channels, one deep and relatively narrow, and the other wide and shallow. Such refinements in the model network, however, should be consistent with the detail (velocity or flow patterns, head fluctuations, etc.) desired. For representing well defined channels such as in the Delta, the network channel widths are merely the mean bank to bank widths. In the case of the Delta these widths approach 4000 feet. For the embayment portions of the San Franciso Bay system the rectangular grid network channels typically have widths of 3000 to 5000 feet. For such embayments a complete overlap of channels may exist, i.e., for a square grid all channels have the same width as length. It is within this overlapping grid network that the two-dimensional flow patterns are represented.

The cross-sectional area of a channel is dependent on the width of the channel and on the head or water surface elevations at the ends (junctions). Since the head fluctuates with time the cross-sectional area is continually changing within the model. For computational purposes an initial cross-sectional area is assigned to a channel which is determined from the heads initially assigned to the junctions at both ends of the channel. As the heads fluctuate a corresponding adjustment is made for the channel cross-sectional area.

The network channels can be assigned "typical" Manning roughness coefficients which are normally associated with natural channels. The coefficients assigned to channels of the San Francisco Bay network vary between 0.018 and 0.050 with the smaller coefficients normally associated with San Pablo and Suisun Bays and the larger coefficients with the channels of the Delta.

An initial estimate of mean channel velocity is required for each simulation run. For an initial hydraulic simulation with the model the mean velocity estimates can be taken as zero. For hydraulic simulations in which only minor changes from some previous hydraulic solution are desired it would be desirable to utilize the mean channel velocities from that previous solution as starting estimates for the new solution. Depending on the significance of the differences in the two hydraulic runs the required computational time to converge to a steady state solution may be significantly reduced by such a procedure.

In applications by FWQA the channel element widths have generally been greater than 10 times the channel depths. For this reason the hydraulic radius for each channel is assumed equivalent to the mean depth of the channel.

Channel widths and lengths can usually be scaled from navigation charts published by the Coast and Geodetic Survey. Depths at mean lower low water (MLLW) can be read directly from these charts and it is usually possible to establish the cross-sectional area from these soundings. The depths have to be adjusted to a datum selected for the model, and for certain channels near the periphery of the network the depths may have to be increased somewhat above those indicated on the charts in order to adequately represent the volume of the system. Since there is no provision for allowing a junction to "run dry" the network is normally extended only to the MLLW line. There is also no provision for increasing or decreasing the surface area of the system as the tide rises and falls. In areas of tidal flats it is therefore necessary to increase the depths of the peripheral channels to adequately represent the volume of the system at higher tidal stages.

## Junction Parameters

The parameters associated with the junctions of the network are surface area, volume, head, and any accretion or depletion from the system.

For junctions in those portions of the network with well defined channels the surface area of a junction is generally taken as the sum of the surface areas of each half-channel entering the junction. For the embayments the surface areas can be determined by laying out a polygon network similar to that of the Thiessen polygon method frequently used for estimating the area of influence of a rain gauge on a watershed. The area for each junction can be computed based on the dimensions of the polygon surrounding it or, for complex polygons, by planimetering. Figure 3 illustrates a typical two-dimensional space as it might be represented by a system of junctions and connecting channels. Channel widths and junction surface areas are indicated in 3(b) and 3(c) respectively.

Junction volumes are computed by multiplying the surface area of the junction by a depth which represents the mean depth of the half-channels (weighted according to surface area) entering the junction. The junction volume varies with time as the head at the junction varies.

The head at each junction represents the elevation of the water surface above a horizontal datum. The selection of the datum is arbitrary, and in fact can be changed from one solution to another. Normally however, the same datum is used for all solutions since it is usually advantageous to utilize the solution from one run as starting conditions for subsequent runs. This procedure minimizes the number of iterations

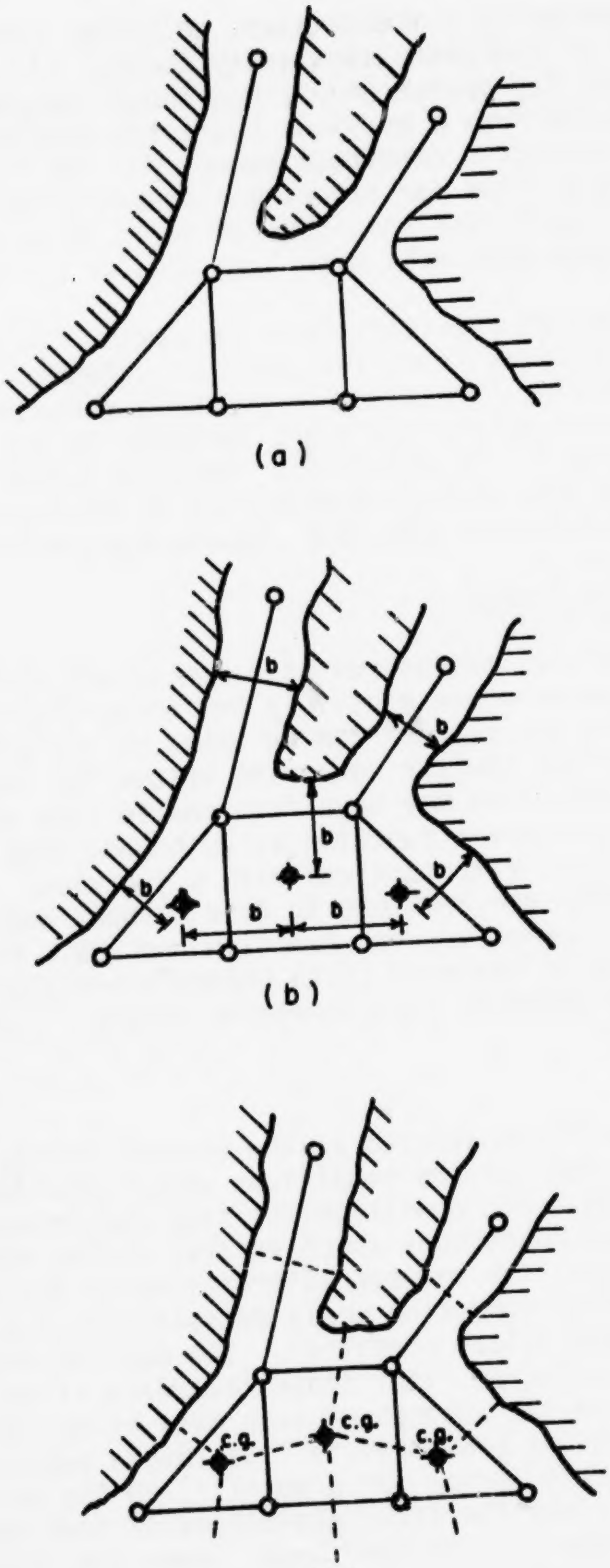


FIGURE 3. TYPICAL CHANNEL AND JUNCTION ELEMENTS

required to converge to a steady state solution, particularly when there is a great deal of hydraulic similarity between the runs. In studies on the San Francisco Bay system [4] it was found that when starting conditions were selected from a previous hydraulic solution which was identical to the desired hydraulic condition except for the location of the Master Drain, the computer time for reaching a steady state solution was from one-third to one-half less than for hydraulic solutions which utilized starting conditions from runs with less similar hydraulic characteristics.

Any accretion or depletion from the system is handled through the addition to, or removal from, the junction volumes. For computational purposes an accretion is assigned a negative value and a depletion is assigned a positive value. At every junction in the network the net accretion or depletion is specified. Inflows, waste water discharges and precipitation are treated identically as accretions and diversions, exportations, consumptive use, and evaporation are treated as depletions.

## Network Numbering System

For computational procedures it is necessary that the junctions of the network be numbered consecutively beginning with one. The assignment of numbers to the network can be based on any arbitrary consideration. A separate but similar numbering system for the channels is also necessary. Each junction may have from one to five channels entering it. A channel must have a junction at each end; thus dead-end sloughs such as occur in the Delta must end with a junction. Associated with each junction number are from one to five channel numbers; and associated with each channel number are two junction numbers. For the Bay-Delta system the network is numbered (both channels and junctions) beginning at the downstream boundary and proceeding generally upstream.

## Tidal Input

The tidal condition imposed at the seaward boundary of the model must be characteristic of the conditions under consideration. For simulation of an historic condition the tide chosen should be representative of the tidal conditions which existed during the period in question. For comparison between alternate waste water disposal plans, a less specific tidal condition would be selected, e.g., a tide representing a mean annual tidal condition. The desired tidal input could be obtained from prototype tidal stage recorders if such were available at the boundary. In the absence of such data it may be necessary to rely on the predictions presented in Tide Tables published annually by the Coast and Geodetic Survey for a point(s) on the model boundary. These projections yield the tidal elevations in feet for the four extreme stages of the tide (higher high, lower low, lower high, and higher low) and the time of occurrence of these four stages. The tidal elevations are then referenced to the datum selected for the model and a harmonic regression analysis performed for obtaining the curve of best fit as defined by a relationship of the form:

$$Y = A_1 + A_2 \text{ Sin } (\omega t) + A_3 \text{ Sin } (2\ \omega t) + A_4 \text{ Sin } (3\ \omega t) + A_5 \text{ Cos } (\omega t) + A_6 \text{ Cos } (2\ \omega t) + A_7 \text{ Cos } (3\ \omega t) \qquad (13)$$

The harmonic analysis program yields the coefficients $A_1$, $A_2$ ....., $A_7$ which, along with the period of the tide, are used in the hydraulic program to define the tidal fluctuation at the lower boundary.

Accretions and Depletions

There is no distinction, within the hydraulic model, between the various water uses, as only the net accretion or loss at a junction is utilized. In fact accretions and losses are assigned a common variable name (QIN) and are distinguished by assigning a negative sign to the accretions to the system. If more than one diversion and/or waste discharge exist in close proximity in the prototype they can be combined into a single net depletion or accretion at a single junction in the model without significantly affecting the hydraulic solution. However, to assure the appropriate quality impact it may be desirable to separate individual waste discharges from diversions and assign them to different junctions.

For studies on the San Francisco Bay system the various hydraulic inputs handled as accretions or depletions at junctions included:

1. Inflows. Inflows include the perennial streams entering the system and can include seasonal streams and storm runoff in studies covering periods when these freshwater sources are significant. Significant groundwater sources can also be included as inflows. Streamflow data are available for historic periods from published U. S. Geological Survey Water Supply Papers for specific basins. These data are generally in the form of mean daily flow for the entire water year with monthly summaries. Synthetically generated hydrologic inputs could also be utilized.

2. Exportations. Exportations include all waters diverted from the basin within the confines of the model network. If diversions are made for exportation from points between the stream gaging station and the model boundary the inflow should be adjusted accordingly. Losses to groundwater can also be included if identifiable.

3. Water Use Within Basin. Waste waters discharged to an estuary resulting from municipal, industrial, agricultural, or other use are handled in one of three ways within the model. The method chosen in any given case is dependent on the specific use of the water and on its origin.

(a) In cases wherein a diversion is made from within the area modeled with subsequent return to the system of all or part of the diversion at a different quality level or at a different location, the diversion and the return are assigned to different junctions. Waters transferred from one point in the estuary to another can be handled in this manner also.

(b) Waste waters discharged to the system but for which the water source originated from outside the modeled area are treated as an accretion to the system, i.e., no diversion is made from the system but a waste discharge is added.

(c) Diversions and return flows can be combined into a net diversion which equals the consumptive loss if such a procedure has no significant effect on the hydraulic or quality characteristics of the system. Cooling water diversions and returns could be included in this category.

4. Evaporation and Precipitation. The net evaporative loss or accretion due to precipitation can be included as a hydraulic input. If climatological conditions are relatively uniform over the entire estuary, a net evaporation or precipitation rate could be applied to the entire water surface area of the estuary to determine the net loss or accretion to the system. This loss or accretion could then be distributed over the system at selected points or could be distributed over every junction if desired.

For an estuary such as the San Francisco Bay-Delta wherein climatological conditions vary markedly over the system a somewhat more complex approach can be utilized. In that system several evaporation and precipitation gauging stations have been established by the U. S. Weather Bureau. The area of influence of each of these stations was determined by constructing Thiessen polygons for the entire area covered by the model. The net evaporation or precipitation rate for each polygon was applied to the surface area of each junction within the polygon to determine the evaporation or precipitation component of the "net" diversion or discharge at each junction.

## Model Execution

During the execution of the program the predicted channel velocities, flows, and cross-sectional areas and the predicted water surface elevations at each junction for each time interval are recorded on magnetic tape or disk. In addition, output in printed form can be obtained at selected time intervals (such as hourly) for a specified number of junctions in the network. The written output includes the elevation of the water surface at each junction as well as the velocity and flow in each of the channels entering the junction. As the solution approaches an equilibrium condition the predicted head for any given junction will repeat itself at an interval equal to the period of the tide specified at the seaward boundary of the system. Although a condition of equilibrium is that the predicted heads repeat themselves at the proper interval, this alone is not necessarily a sufficient test for equilibrium as a relatively minor change in head during a time interval can represent a significant flow change. This is particularly true for junctions with large surface areas where even a change of 0.01 foot in the water surface elevation can represent a significant quantity of water. A more reliable test for equilibrium of the hydraulic solution is comparison of the net flows computed in the program against those computed from the program inputs. The net flow past a point in the system can be computed by algebraically summing all inflows, diversions, returns, exportations, etc. which are used as inputs for the run, with the stipulation that the summation include all such depletions and accretions to the system upstream from a plane cutting completely through the network at the point. As the hydraulic solution approaches equilibrium the combined net flow through the channels cut by the plane will approach the computed value.

In its present state the model component for computing net flows is run as a subroutine of the hydraulic program. The subroutine utilizes as input the tape or disk written in the hydraulic program. Normally the predicted velocities, flows, and heads for each time interval over the last full tidal cycle of the hydraulic solution are utilized for computing the net flows in that they should be the most representative of the equilibrium solution. For purposes of extracting, the full tidal cycle is divided into a whole number of equal intervals each of which is some whole multiple of the basic time interval used in the hydraulic program. As will be discussed in a later section the interval at which the hydraulic parameters (velocity, flows, and heads) are extracted is usually dictated by the choice of the time interval used in the quality program. The extracted hydraulic parameters are stored on tape for subsequent input to the quality program. In addition a printout of the net flows is obtained for each of the channels in the network.

## QUALITY MODEL THEORY

A constituent introduced into the waters of an estuary is transferred from one point to another by two basic transport mechanisms, advection and diffusion. A portion of the constituent may be removed from the system along with the water extracted for municipal, industrial, or agricultural purposes or for exportation. The concentration of a constituent is also affected by waste water discharges, by biological or chemical decay, and by mass transfer between the water surface and the atmosphere.

Transport by advection is primarily a hydraulic mechanism and moves the constituent in the direction of flow. Transport by diffusion on the other hand is primarily dependent on the concentration gradient between two points and can take place in a direction opposite the flow. Longitudinal dispersion of a constituent which in the prototype results from the non-uniform velocity distribution at a cross-section, is not specifically represented since the predicted channel velocity in the model is the mean velocity across the flow section.

The water quality component of the mathematical model is very closely tied to the hydraulic component discussed previously. The solution of the quality program is based on the dynamic steady-state hydraulic condition predicted in the hydraulic program. As was discussed previously, the hydraulic parameters (velocities, flows, heads) for each time interval are normally stored on tape or disk and form the basis for the hydraulic inputs into the quality program. Whereas the time interval in the hydraulic program is relatively small (50 to 300 seconds) the time interval used in the quality program is much larger (900 to 3600 seconds). The average flows and heads for the larger time interval are determined in a separate hydraulic extract subroutine. These condensed parameters for the full tidal cycle are stored on tape or disk for input into the quality program and thus can form the hydraulic basis for any number of quality runs. The quality solution proceeds over a full tidal cycle at which point the hydraulic input tape is rewound and used again as the basis for the succeeding cycle.

Five constituents can be handled simultaneously including both conservative and non-conservative constituents and including the interrelationship between biochemical oxygen demand (BOD) and dissolved oxygen (DO).

The model can be used to predict the dynamic steady-state concentrations at every junction in the network resulting from a specified set of boundary conditions (tidal conditions, inflows, waste discharges, diversions, exportations, etc.).

The rate of buildup of a constituent can also be computed by the model. For example, in the verification studies discussed in Part II the rate of salinity incursion in the San Francisco Bay system during two historic periods was simulated.

The model is extremely flexible and can easily accomodate changes in the physical configuration of the prototype or in the operation of the water resource system. For any proposed physical or operational change in the system, the hydraulic program can first be used to predict the changes in hydraulic behavior of the system and then the quality program can be used to predict the effect of these changes on quality.

## Advection

Advection or advective transport is the transport of a particular mass of a constituent at a rate equivalent to the velocity of the volume of water with which the constituent is associated. This can be expressed as:

$$T_a = u\ c \tag{14}$$

where $T_a$ is the advective transport through a unit area in a unit time, u is the velocity of the water, and c is the concentration of the constituent in the water. The time rate of change of concentration, $\partial c/\partial t$, in a given element, i, of the system is dependent on the mean velocity in the element, $U_i$, and on the concentration gradient through the element. This relationship can be expressed as:

$$\frac{\partial c}{\partial t} = U_i \frac{\partial c}{\partial x} \tag{15}$$

Each of the terms of equations (14) and (15) are functions of space and time.

## Eddy Diffusion

Whenever a concentration gradient is established in water, a mechanism is established for the transfer of the constituent from the regions of high concentration to those of a lower concentration. For a quiescent body of water, this transport (molecular diffusion) is extremely slow. The transfer rate is greatly increased in a non-quiescent or turbulent body of water as a result of eddy currents. The term eddy or turbulent diffusion is frequently used to describe this transport process in a turbulent body of water. This process may be expressed as:

$$T_d = K_d \frac{\partial c}{\partial x} \tag{16}$$

where $T_d$ is the turbulent transport by diffusion through a unit area in a unit time, $K_d$ is a coefficient which describes the rate of transfer, and $\partial c/\partial x$ is the concentration gradient of the constituent under consideration. For a given element of the system in which the diffusion coefficient $K_d$ can be assumed constant, the time rate of change of the constituent $\partial c/\partial t$ is dependent on the second derivative of c with respect to x, as follows:

$$\frac{\partial c}{\partial t} = K_d \frac{\partial^2 c}{\partial x^2} \tag{17}$$

As with equations (14) and (15) the direct solution of equations (16) or (17) is normally possible only for relatively simple cases.

## Combined Transfer Equation

The processes of advective transport and eddy diffusion act as independent phenomena. Combining equations (15) and (17) the net rate of change of concentration is:

$$\frac{\partial c}{\partial t} = U_1 \frac{\partial c}{\partial x} + K_d \frac{\partial^2 c}{\partial x^2} \qquad (18)$$

Equation (18) can be applied to an element of the system if the following assumptions are not violated:

1) the element is completely mixed vertically,
2) the velocity U is the mean velocity in the cross-section,
3) the flow and transport within the element are unidirectional (one-dimensional flow), and
4) the mean velocity U and $K_d$ are constant throughout the length of the element within the computational time increment.

## Longitudinal Dispersion

Although the flow of a channel can be represented by a mean velocity, in actuality the velocity varies from point to point in the cross-section. Thus, in a given channel, a certain portion of the flow advances at a rate higher than the mean velocity and a certain portion advances at a lower rate. The mechanism through which liquid particles (and any associated constituent) undergo relative displacement due solely to the difference in velocities along adjacent streamlines is termed longitudinal dispersion. Since the velocity in equation (18) is assumed to be the mean velocity at the cross-section this dispersion phenomenon is not specifically represented. Although the numerical solution technique utilized does result, coincidently, in the longitudinal dispersion of a constituent this coincidental transfer is only partially controlled and is not a true representation of the longitudinal dispersion process. This phenomenon will be discussed in more detail in subsequent sections.

## Finite Difference Form of Transport Equation

For the network of channels and junctions which characterizes a system it is convenient to express total transport by equations (14) and (16).

$$T_t = T_a + T_d = U_1\, c + K_d \frac{\partial c}{\partial x} \qquad (19)$$

where $T_t$ is the total transport per unit area per unit time. Applied to a discrete channel, equation (19), in finite difference form becomes:

$$\frac{\Delta M}{\Delta t} = A_i U_i c^* + K_d A_i \frac{\Delta c}{x_i} \tag{20}$$

where M is the mass of pollutant transported, $A_i$ is the cross-sectional area of the channel i under consideration, $U_i$ is the mean velocity in the channel during the time interval $\Delta t$, $\Delta c$ is the difference in concentrations at each end of the channel, and $x_i$ is the channel length. The concentration $c^*$ is a representative concentration of the water advected and is dependent on the concentration gradient that exists over the channel length and on the direction of flow in the channel.

The computational procedure for advective transport results in longitudinal dispersion since the constituent is moved from one junction to another during a single time interval while the water itself typically moves a portion of the channel length. This phenomenon has been termed "induced advective dispersion" [1] or "numerical mixing" [7] and is controlled through the specification of the concentration $c^*$ in equation 20.

## Diffusion Coefficient

It has been demonstrated [11] that the diffusion coefficient $K_d$ is dependent upon the rate of energy dissipation in the system and on the scale of the phenomenon. This can be expressed as:

$$K_d = C_1 E^{1/3} L_e^{4/3} \tag{21}$$

where E is the rate of energy dissipation per unit mass, $L_e$ is the statistical mean size of eddies participating in the mixing process, and $C_1$ is a function of relative channel roughness. For water flowing at a uniform depth at a steady mean velocity U, the rate of energy dissipation in foot pounds per pound of water per foot of channel length is equal to the slope of the energy grade line. The reciprocal of the mean channel velocity, 1/U, defines the time interval over which the energy loss occurs. The mass of each pound of water is 1/g. The rate of energy dissipation per unit mass in a channel can therefore be represented by:

$$E = \frac{dH/dx}{1/g \; 1/U_i} = U_i \, g \, \frac{dH}{dx} \tag{22}$$

The mean eddy size $L_e$ can be related to a dimension of the channel such as the width or depth. Utilizing the depth y as a measure of scale and defining the slope of the energy line by Manning's equation, equation (21) becomes:

$$K_d = C_3 U_i y^{8/9} \tag{23}$$

where

$$C_3 = \frac{C_1 C_2^{4/3} g^{1/3} n^{2/3}}{(1.486)^{2/3}} \tag{24}$$

and

$$C_2 = \frac{L_e}{y} \tag{25}$$

For computational purposes it is convenient to replace the channel depth with the hydraulic radius and simplify equation (23) to:

$$K_d = C_4 \; |U| R \tag{26}$$

where $K_d$ has dimensions length squared over time. The absolute value sign is included to indicate that the transport by eddy diffusion is independent of the direction of flow in the channel and depends only on the sign of the concentration gradient as indicated in equation (20).

For early studies with the model [1] $C_4$ was taken as 0.042. Subsequent FWQA studies utilizing $C_4$ values ranging between zero and 5.0 indicated that transport by diffusion in the model is relatively insignificant when compared to transport by advection. For studies on the San Francisco Bay system, $C_4$ was taken as 0.025.

## Degradation and Mass Transfer

The concentration of a non-conservative pollutant, such as a municipal or industrial organic waste can be biochemically converted or stabilized to matter which is stable. The rate at which the organic matter is stabilized is directly proportional to the amount of unstabilized material remaining and is expressed mathematically as:

$$\frac{dL}{dt} = -K_1 L \tag{27}$$

where L is the concentration of pollutant at time t as measured by the biochemical oxygen demand (BOD), and $K_1$ is the reaction rate with dimensions 1/time. Equation (27) can be integrated to yield the relationship defining the concentration at any time:

$$L_t = L_o e^{-K_1 t} \tag{28}$$

where $L_o$ is the concentration at time zero and e is the base of the Naperian logarithms. Expressed in finite difference form and applied to the mass of unstabilized material remaining in a junction j of the model network, equation (28) becomes:

$$M_j = -K_{1j} \; L_j \; V_j \tag{29}$$

where $M_j$ is the total mass remaining at the end of the time step, $L_j$ is the concentration of the unstabilized material at the beginning of the time interval, $V_j$ is the volume of the junction, and

$$K_{1j} = e^{-K_1 \Delta t} \tag{30}$$

which is dimensionless.

The dissolved oxygen in a body of water is depleted by an amount equivalent to the BOD exerted. The oxygen in the system is naturally replenished through the process of mass transfer at the surface. This rate can be expressed as:

$$\frac{dD}{dt} = -K_2 D \tag{31}$$

where D is the saturation deficit and $K_2$ is the reaeration coefficient, with dimensions 1/time, describing the rate of the reaction. The saturation deficit D is the difference between the saturation concentration and the actual concentration. The overall effect of reaeration and decay on the saturation deficit is:

$$\frac{dD}{dt} = K_1 L - K_2 D \tag{32}$$

Although equation (32) can be integrated to yield a single expression defining the saturation deficit at any time it was more convenient for computational purposes to separate the reaeration and decay effects. Equation (29) defines the mass of BOD exerted during each time interval which is equivalent to the mass of oxygen depleted during the time interval. The deficit of any time, t, is obtained by integrating equation (31):

$$D_t = D_o e^{-K_2 t} \tag{33}$$

where $D_o$ is the deficit at time zero. Equation 33 was expressed in finite difference form and applied to the saturation deficit existing at a junction in the network, such that:

$$\Delta O_j = -K_{2j} \;\; D_j V_j \tag{34}$$

where $\Delta O_j$ is the mass of oxygen replenished, $D_j$ is the saturation deficit concentration existing at the junction, $V_j$ is the volume of the junction, and

$$K_{2j} = 1.0 - e^{-K_2 \; \Delta t} \tag{35}$$

which is dimensionless.

The reaeration coefficient $K_2$ is highly dependent on the degree of fluid turbulence existing in the system. This is commonly related to the velocity and depth of the fluid in the general form:

$$K_2 = C\, U^a\, y^b \tag{36}$$

where C is a constant, U is the velocity of the fluid, y is the depth of the fluid, and a and b are exponents. There is not universal agreement on the most suitable values for C and the two exponents. These parameters are determined empirically and therefore may be biased toward an investigator's selection of experiments. A summary of these parameters found in three investigations [1] is presented in Table 1 for $K_2$ expressed as $\text{day}^{-1}$, U in feet per second, and y in feet.

TABLE 1. SUMMARY OF COEFFICIENTS FOR DEFINING REAERATION RATE

| Investigator | C | a | b |
|---|---|---|---|
| O'Connor and Dobbins | 12.9 | 1/2 | -3/2 |
| Churchill et al | 11.5 | 1 | -5/3 |
| Krenkel and Orlob | 2.5 | 1 | -1 |

It is not apparent which of three resulting expressions would best represent the reaeration rates in any particular estuary. In many estuaries photosynthetic production of oxygen and respiration by algal populations may play significant roles in the oxygen balance of the system. These phenomena have not as yet been sufficiently defined, functionally such that they could be incorporated into the mathematical model. Because of these and other factors, no attempt has been made to relate $K_2$ to any hydraulic or biological parameters within the model although it would not be difficult to do so.

## Import and Export

The total mass of constituent present in the system may be changed by one or more of four principle mechanisms: 1) by introduction as a part of the inflow to the system (whether it be a river inflow, tidal inflow, or a waste discharge), 2) by removal from the system in water diverted or exported, 3) loss from the system by decay, or 4) addition through reaeration. Within the system the distribution and fate of the constituent is governed by the functional relationships presented previously.

The mass of constituent introduced at each junction in the system during each time interval is equivalent to:

$$\Delta M_j = Q_j \, c \, \Delta t \qquad (37)$$

where $\Delta M_j$ is the total mass of constituent added to the system $Q_j$ is the inflow to the system at junction j, c is the concentration of the constituent in the inflow, and $\Delta t$ is the time interval. Equation (37) is also used to compute the total mass of constituent lost from each junction. For a diversion, however, the concentration c is taken as the concentration existing in the system at junction j whereas, for an inflow, the concentration must be specified. It should be pointed out that $Q_j$ in equation (37) does not affect the hydraulics of the system but is used merely as a basis for either adding or removing the appropriate mass of constituent during each time interval. Since the effect of any waste discharge or diversion in the hydraulic model is automatically carried over to the quality model (through its effect on the junction volume) it is imperative that $Q_j$ (and c for a discharge) be specified in the quality model to assure the appropriate rate of withdrawal of mass from (or discharge to) the system.

## Summary of Finite Difference Formulations

The basic formulations governing the distribution and fate of a constituent in the quality model can be summarized as follows:

a. Advection (and longitudinal dispersion)

$$\Delta M_a = A_i \, U_i \, c^* \, \Delta t \qquad (38)$$

b. Eddy Diffusion

$$\Delta M_d = K_d A_i \, \frac{\Delta c_i}{x_i} \, \Delta t \qquad (39)$$

c. Degradation — Decay

$$\Delta M_b = (1.0 - K_{ij}) \, L_j \, V_j \, \Delta t \qquad (40)$$

d. Reaeration

$$\Delta M_o = K_{2j} \, D_j \, V_j \, \Delta t \qquad (41)$$

e. Import — Export

$$\Delta M_e = Q_j \, c_j \, \Delta t \qquad (42)$$

where:

$\Delta M_a$ = the mass advected from the junction at the upstream end of channel i to the downstream junction

$A_i$ = cross-sectional area of channel i during time step $\Delta t$

$U_i$ = mean velocity in channel i

$c^*$ = concentration of the advected water

$\Delta t$ = time step

$\Delta M_d$ = the mass of constituent transferred by diffusion from the junction of higher concentration to that of lower concentration, through channel i

$K_d$ = the diffusion coefficient in channel i during the time step $\Delta t$

$\frac{\Delta c_i}{x_i}$ = the concentration gradient over channel i which has length $x_i$

$\Delta M_b$ = the mass of constituent lost through decay or degradation during time step $\Delta t$

$K_{1j}$ = a dimensionless factor, computed from equation (30), which specifies the loss per time step at junction j

$L_j$ = concentration of non-conservative constituent existing at junction j during time step $\Delta t$

$V_j$ = volume of junction j during time step $\Delta t$

$\Delta M_o$ = the mass of oxygen added to junction j by reaeration during time step $\Delta t$

$K_{2j}$ = a dimensionless factor, computed from equation (35), which specifies the fraction of the existing saturation deficit that is replenished each time step

$D_j$ = the dissolved oxygen saturation deficit occurring during the time step $\Delta t$

$\Delta M_e$ = the mass of constituent removed from the system in the diversion $Q_j$ at junction j during time step $\Delta t$, or the mass of constituent added to the system in the waste discharge $Q_j$ at junction j

$c_j$ = the concentration existing at junction j if $Q_j$ is a diversion or the concentration specified if $Q_j$ is a waste discharge

Equations (38) and (39) represent the individual components of the combined transport formulation presented as equation (20) previously. For convenience these components are treated separately in the program.

## Solution Technique

Conservation of mass within the model is maintained at the network junctions. Equations (38) through (42) describe the transfers of mass between junctions and the loss or addition of mass at a junction. Specified for each junction is an initial volume and an initial concentration which determines the associated total mass of constituent initially present within each junction. Also specified is the net discharge (and associated constituent concentration) or withdrawal at each junction.

A quality constituent is distributed in the system in a stepwise procedure as follows:

1. Hydraulic parameters are read from the input tape (which was generated in the hydraulic solution). These include:

   a) the head (water surface elevation) at each junction at the start of the time step

   b) the flows between junctions during the time step

2. Transfers of constituent are made between junctions based on:

   a) advection -- The mass transferred is equal to the product of the flow and a representative concentration.

   b) diffusion -- The mass transferred is proportional to the concentration gradient between the junctions.

   The solution proceeds from one channel element to another with advective transfers made from the upstream junction to the downstream junction (as determined from the direction of flow during the time step) and diffusive transfers made from the junction of higher concentration to the other. The net mass transfer through each channel is removed from the appropriate junction and immediately added to the junction at the other end of the channel to maintain a mass balance. The solution proceeds through all channel elements before passing to step 3.

3. If the constituent is non-conservative the mass in each junction is decayed by applying a decay coefficient. If the constituent is dissolved oxygen a reaeration coefficient is applied. These adjustments are made at all junctions before passing to step 4.

4. Contributions of constituent from net inflows are added to each junction.

5. Withdrawals of constituent by diversions at each junction are made. Steps 4 and 5 are completed for all junctions before passing to step 6.

6. The water surface elevation at each junction for the beginning of the next time step is read from the hydraulic input tape and the volume of each junction is adjusted to that elevation.

7. The new total mass in each junction is divided by the new volume to determine the new concentration.

8. The new flows between junctions are read from the hydraulic input tape.

9. Steps 2 through 8 are repeated a specified number of times.

In steps 2 through 5 above there is no adjustment during the time step, of the existing concentration at each junction, i.e., all losses, additions, and transfers are applied to the existing mass at each junction and not to the concentration. It is only after all adjustments of the total mass have been made during a time step that a new concentration is computed (step 7).

The representative concentration used in the advective transport equation (38) is determined from a weighted average of the concentrations existing at the junctions at both ends of the channel in which the transfer is being made. A discussion of the selection of the weights used in model studies for the San Francisco and San Diego Bay systems is included in a later section.

The quality solution can start at any desired point on the tidal cycle. At the completion of each tidal cycle the hydraulic input tape is rewound and used again.

## QUALITY MODEL APPLICATION

Because the water quality program utilizes the identical network developed for the hydraulic program, no additional "modeling" effort is required to represent the physical parameters of the prototype. Application of the quality program to a particular system therefore consists primarily of defining the various rate coefficients for diffusion, decay, and reaeration and of specifying the various inputs required. Under certain conditions it may be necessary to incorporate other factors into the quality program, e.g., the effects on quality of evaporation or of agricultural use. Provisions are included in the quality program to handle these phenomena in a special way.

## Input Requirements

While many of the inputs required for the quality model present no particular difficulty others may require very careful selection and consideration for certain types of problems.

Time Interval. The structure of the model is such that the computational time interval can be varied from run to run. There are certain restrictions on the quality time interval, however. Namely, 1) that it be some whole multiple of the time interval in the hydraulic program, 2) that it be such that the period of the tide used in the hydraulic solution is some whole multiple of it, and 3) that it be such that the quality solution remains stable. As an example, for a hydraulic solution utilizing a 100-second time interval and a tide with a 25.0 hour period the quality program could utilize a 1/4, 1/2, or 1 hour time interval (among others) provided the solution remains stable. On the other hand, for a hydraulic solution utilizing the same 100-second time interval but with a 24.5 hour tide a one hour time interval for the quality solution could not be used since the 24.5 hour period cannot be divided into a whole number of one-hour intervals.

Experience with the quality program in simulating several historical conditions indicates that a one-half hour time interval is more than adequate to describe the quality fluctuations due to the tidal motion in the San Francisco Bay and Delta system.

Inflows. One of the principal sources of many constituents is the freshwater inflow to the system. The flow of each of the streams entering the system must be specified along with the concentration of the constituent (s) under consideration.

Waste Discharges. For computational purposes there is no distinction within the model between a waste water discharge and an inflow. The contribution of constituent to the system from each is normally identified by specifying a flow and associated concentration. Because of certain problems associated with some agricultural waste waters special provisions were incorporated to handle these wastes. This special problem is discussed in more detail in a later section.

Diversions. The quality of any diversion for exportation, or for local use, is the concentration existing at the point of the diversion during each time interval. Water leaving the system at the seaward boundary also leaves at the concentration existing at the boundary.

Boundary Conditions. Of the various inputs to the quality program one of the most significant is the specified quality condition at the seaward boundary of the network. If the situation permits, the model should extend to the sea, a sump of known concentrations; otherwise, the problem is one of estimating the appropriate concentration-tidal stage relationship. This problem is illustrated in the various case studies presented in Part II.

Starting Conditions. Similar to the problem of establishing the boundary concentration is the problem of initial concentrations at all junctions. For certain studies these concentrations are defined by the problem, i.e., the concentrations are historical concentrations or those resulting from a previous study. If the problem is to determine the dynamic steady state concentrations resulting from given inputs, it is desirable to minimize computation time by selecting as starting concentrations the estimated final concentrations. If the starting concentrations are too low, such that insufficient mass is present in the system, the additional mass must be added through the various specified inputs, i.e., waste discharges, inflows, or the flooding tide. Similarly if the starting concentrations are too high, the excess mass must be flushed from the system. A similar problem is that of starting with an improper distribution of consituent in the system.

To reduce the computation time required to achieve a steady state quality solution, provision was made to increment the mass of constituent in selected areas of the model. This feature was used either to adjust the final solution from one quality solution to serve as the starting conditions for a similar quality solution based on a different hydraulic condition, or, to adjust the concentrations in the system after running the program for a specified number of tidal cycles and evaluating the results. Thus, if the concentrations in one area were increasing while those in another were decreasing, a factor greater than unity would be applied to the concentrations existing in the first area and a factor less than unity to those in the latter area. The relationship utilized was such that:

$$c_{ja} = c_j f \qquad (43)$$

where $c_{ja}$ is the adjusted concentration at junction j after applying the factor f to the existing concentration $c_j$. Equation (43) can be applied to up to ten specified groups of consecutively numbered junctions for each constituent. A solution is evaluated after a short simulation, the factors applied, and the solution continued for a specified period. This process can be repeated any number of times until the steady state solution is achieved. Even with limited experience in evaluating the results and applying the factors the average computation time to reach a steady state solution can be cut significantly.

## Special Considerations

Additional factors which can significantly affect the quality of the waters of an estuary include evaporation, precipitation, and agricultural use.

Precipitation and Evaporation. The dilutional effect of precipitation which falls directly on the water surface is relatively insignificant. However the increase in freshwater flow through the system due to precipitation may result in a more effective hydraulic barrier against incursion of seawater into the estuary with significant improvement in mineral quality. The reduction in flow caused by evaporation has the opposite effect.

The importance of evaporation and precipitation as they affect water quality can perhaps best be evaluated by considering the magnitude of the contribution of each to the overall hydrology of the system. Evaporation and precipitation, as considered here, is that quantity of water either lost from or added to the water surface of the estuary. Evaporation in this sense does not include evapotranspiration from adjacent lands nor does precipitation include local runoff as these factors can be included as separate inputs. For the San Francisco Bay system, in a month such as July, when precipitation is normally zero, evaporation from the channels of the Delta alone totals approximately 29,500 acre-feet. For a winter month such as January, the net precipitation (precipitation minus evaporation) which falls directly on the Delta channels normally totals 8,660 acre-feet. It is obvious that for conditions of low controlled Delta outflow (1500 cfs or 92,000 acre-feet per month), these contributions are not insignificant. The net outflow is further decreased by evaporation from Suisun Bay of 21,400 acre-feet and 46,300 acre-feet from San Pablo Bay during a month such as July.

Although it would be possible to include the effects of precipitation on water quality by treating it as an inflow with zero concentration, another treatment proved more convenient. Advantage is taken of the fact that the hydraulics of the system are not altered or affected by any input into the quality program. In the hydraulic program, precipitation is included as an inflow to each junction but it is not included as inflow in the quality program. The result is to add water but not constituent. In the same way, evaporation is included in the hydraulic solution but not in the quality solution. Hence, water is removed but not constituent.

Agricultural Use. In one sense evapotranspiration from adjacent agricultural lands is identical to evaporation from the water surface of the system, i.e., they both account for a consumptive loss of water from the system. From the quality standpoint, however, their effects are somewhat different. When water is lost from the surface of a channel or bay by evaporation the effect on quality is immediate, that is, water is removed but the constituent remains in the channel resulting in an increase in concentration of the constituent.

Water used consumptively by agriculture, however, is first diverted from a channel to a tract (either through direct diversion or by seepage) and with it is diverted associated constituents. The diversion (or seepage from a channel) per se does not directly affect the quality of the remaining water. As the water is used consumptively, the salts or other constituents accumulate in the soil or are returned to the channel in the drainage water. If the buildup of salts is allowed to continue, the soil will eventually become unsuitable for the raising of crops. The soil salt buildup may be controlled through the application of water in excess of plant needs and by percolation of this excess water through the root zone of the plant. The resulting leachate will contain, in addition to the original salt content, those salts formerly present in the water lost through evapotranspiration and any salts dissolved from the soil.

Where surface irrigation is practiced salt accumulation can normally be controlled through the normal irrigation practice with the excess water (leachate) either percolating down to the ground water or being collected in drainage tile and returned to the channels.

For tracts irrigated by subsurface methods (such as practiced in the Delta of the San Francisco Bay system) water reaches the root zone by capillary movement upward from the water table. The salts which move upward with the irrigation water into the root zone remain there when the water is removed by evapotranspiration. Thus salts tend to accumulate in the soil during the irrigation season. In the late fall or winter leaching of these salts is accomplished by precipitation and the application of excess quantities of water to the land and the accumulated salts are returned to the channels. On a long term basis there is an approximate salt balance maintained, i.e., the salt diverted to a tract equals the salt removed. For certain tracts leaching may be necessary every year, while for others small quantities of salts may be allowed to build up for several years before leaching is required. On a short term basis (such as a month), there may be a net increase of salts on a tract (during months of the irrigation season) or a net decrease (during months leaching is carried out). The quality of the water in the channels is not improved merely because more salts are removed than returned during a certain month as the concentration of salts in the drainage water is invariably as high or higher than that in the applied water. During months when leaching is carried out, the concentration of salts in the drainage water may be very much higher than that applied, resulting in a significant increase in concentration in the channels.

For the San Francisco Bay system data were available to relate the total mass of a particular constituent returned in agricultural drainage in a given time period to the total applied in that period, as follows:

$$Q_d c_d = m Q_a c_a + b \qquad (44)$$

where:

$Q_d$ = flow rate of drainage, cfs

$c_d$ = concentration in drainage flow

$Q_a$ = flow rate of applied water, cfs

$c_a$ = concentration in applied water

$m$ = return factor

$b$ = return constant (mass units)

The Delta agricultural tracts were grouped into study units and the various terms in equation (44) determined on a monthly basis. Depending on the constants m and b, a constituent can either be stored on a tract, removed at the same rate applied, or removed at a rate exceeding the rate applied.

# PART II. MODEL TESTING, VERIFICATION, AND CASE STUDIES

## INTRODUCTION

Regardless of the theory on which a model such as the one described herein is based the real test of its utility lies in its capability to adequately reproduce prototype behavior. The difficulties associated with simulating the hydraulic and water quality behavior of a complex estuarial system are many and complex. As discussed heretofore many simplifying assumptions are necessary to apply the governing equations to an estuary. Discretizing the system and numerical solution of the equations involve additional simplifications which can affect the predicted distribution of a constituent.

In addition to these problems associated with the model structure there can also be significant difficulties associated with the quality and quantity of prototype data for verification. Data to sufficiently define the entire hydraulic regime and the distribution of quality constituents throughout the system are rarely, if ever, available. Extreme care must therefore be exercised in selecting test cases for verification. Prototype behavior continuously changes as governed by changing hydrologic, tidal, and other conditions. Although there is nothing inherent in the model structure to preclude the inclusion of such factors as variable inputs, the inadequacy of data on prototype behavior in most cases would not justify such a refinement.

Numerous studies for testing and verifying the hydraulic and water quality models have been conducted both by Water Resources Engineers, Inc. (WRE) and FWQA. Certain studies were conducted with an idealized linear estuary to determine the sensitivity of model behavior to various model parameters. Additionally model behavior has been tested by FWQA on the San Francisco and San Diego Bay systems.

## SAN FRANCISCO BAY-DELTA SYSTEM

Verification of the hydraulic and water quality models was obtained by comparing predicted hydraulic and quality conditions with those observed in the prototype. The ability to simulate tidal characteristics such as stage, phase, and flow was investigated together with its ability to adequately represent such quality considerations as salinity incursion, repulsion, and the dispersion of a pollutant from a point source. Numerous verification studies on the San Francisco Bay system were made by WRE prior to FWQA acceptance of the models; the results of these studies are not included here. This discussion is limited to additional studies by FWQA.

## Hydraulic Model Verification

The extent to which the hydraulic model can be verified is largely dependent on the availability of measurements of prototype behavior. For the system under consideration there are extensive records available from many permanently installed tidal stage recorders throughout the Bay-Delta system. There have also been limited investigations by various local, State, and Federal agencies for determining specific hydraulic characteristics such as tidal flows in certain channels or flow splits between key channels of the Delta. Other sources of information on the hydraulic behavior of the Bay and Delta are the Tide Tables and Current Tables published annually by the Coast and Geodetic Survey.

The historical periods suitable for verification purposes are limited to those periods where hydraulic and quality data are both adequate. In particular the periods of July 1955 and September 1955 were selected to demonstrate the model's ability to simulate salinity incursion (July) as well as salinity repulsion (September). Although a part of the required historical input data for the hydraulic model (river flows, tidal conditions, exportations) were available on a daily basis, other data were available only on a monthly basis (agricultural consumptive use and evaporation). Thus mean monthly hydraulic conditions were used for the two months in question.

Tidal conditions for the two months were obtained from actual tidal records maintained by the Coast and Geodetic Survey for the Golden Gate station. The mean tide for each of the two months was computed on the basis of averaging each of the four stages of the tide (higher high, lower low, lower high, and higher low). Similarly the average durations of rise and fall were computed for each of the four stages. The daily recorded tide during the period in question which most closely approximated this "mean" tide was chosen as the actual input tide. This tide was then projected to the model boundary at the entrance to San Pablo Bay (Point Orient) using the Tide Tables. The tides imposed at the model boundary for the July and September 1955 hydraulic runs are illustrated in Figure 4.

Municipal and industrial diversions and waste water returns for the two months in question were obtained from published data [12, 13, 14, 15]. Streamflows, exportations, and agricultural diversions and return flows were obtained from publications of the California State Department of Water Resources [16, 17]. Precipitation and evaporation data from U. S. Weather Bureau publications and from a published report of the U. S. Army Corps of Engineers [18] were used for determining the net evaporation loss from the system for the two months. A summary of the hydraulic inputs to the system indicated levels of net Delta

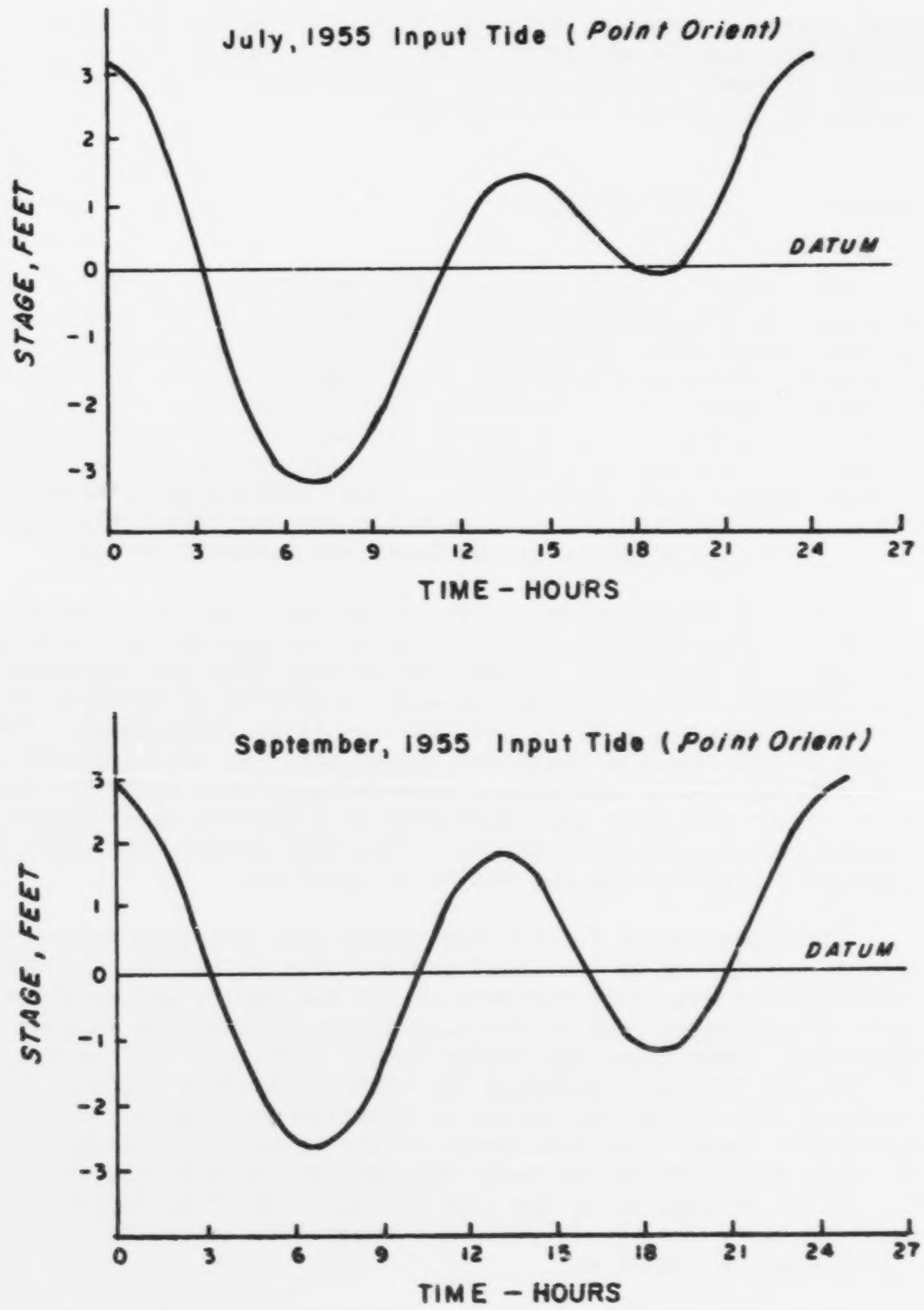


FIGURE 4. TIDAL INPUTS AT SEAWARD BOUNDARY--SAN FRANCISCO BAY-DELTA

outflow (past Chipps Island) of 1570 cfs for July 1955 and 5540 cfs for September 1955.

Results of the 1955 July and September runs indicated excellent agreement between model predictions and prototype data. To illustrate the model behavior the results of the July 1955 and September 1955 runs for several stations are presented in Figures 5 and 6.

In addition to the tidal stage and phase comparisons, it was possible to make comparisons between net flows in certain Delta channels as predicted in the model with prototype net flows as predicted by relationships developed by the California Department of Water Resources [19]. These comparisons are summarized in Table 2.

TABLE 2. NET FLOWS IN DELTA CHANNELS

| | July 1955 | | Sept. 1955 | |
|---|---|---|---|---|
| | DWR Prediction* (cfs) | FWQA Model (cfs) | DWR Prediction* (cfs) | FWQA Model (cfs) |
| Sac. River @ Sac. | 8990** | 8990** | 9841** | 9841** |
| Sutter Slough | 1550 | 1539 | 1750 | 1811 |
| Steamboat Slough | 820 | 670 | 1000 | 795 |
| Delta Cross-Channel | 2950 | 2916 | 3100 | 3177 |
| Georgiana Slough | 1850 | 1561 | 1950 | 1755 |

*Empirical relationship **Specified

## Quality Model Verification

Three separate studies were made with the quality program for purposes of additional verification. Two of these involved simulation of quality changes during historic periods (July 1955 and September 1955). The third study involved the simulation of a continuous tracer release from a point source.

Salinity Incursion and Repulsion. The projected increase in export and consumptive use of waters normally flowing to the Bay-Delta system has raised questions about the adequacy of the proposed minimum flows. The relationship between Delta outflow and salinity levels in the western Delta and the historical significance of salinity incursion made it essential that the model adequately represent this phenomenon. Historical periods of seawater incursion (July 1955) and repulsion (September 1955) were selected for simulation.

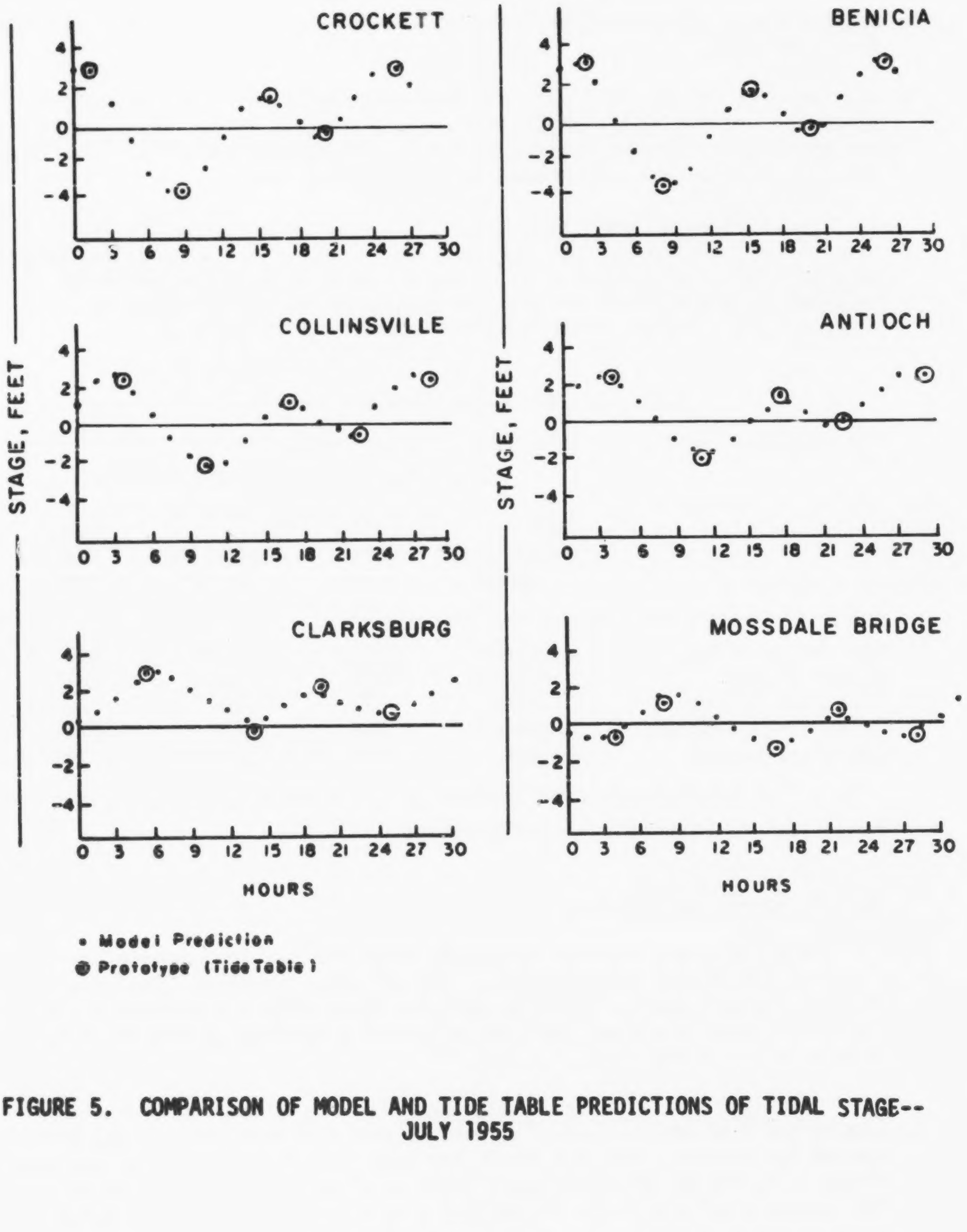


FIGURE 5. COMPARISON OF MODEL AND TIDE TABLE PREDICTIONS OF TIDAL STAGE--JULY 1955

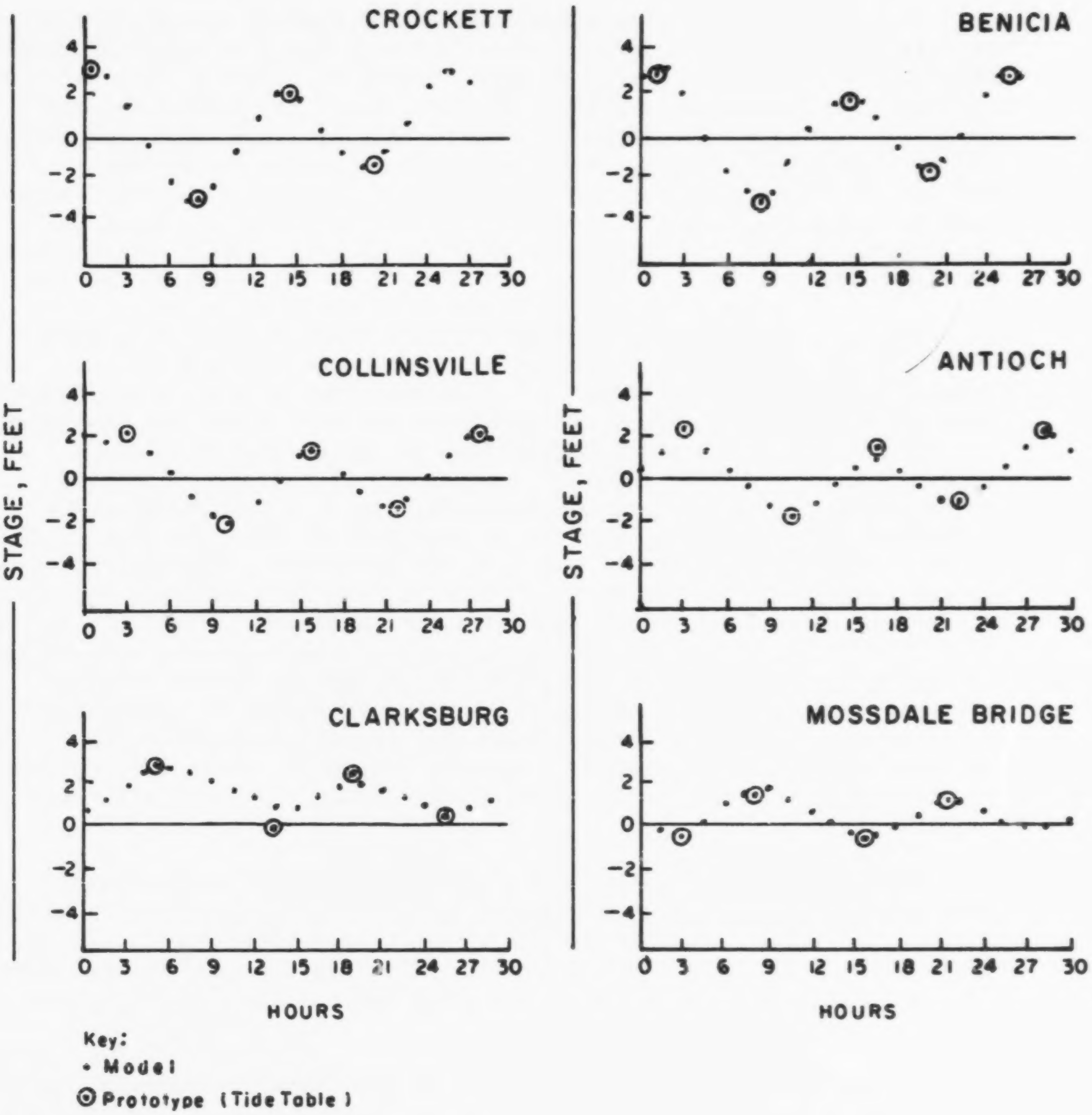


FIGURE 6. COMPARISON OF MODEL AND TIDE TABLE PREDICTIONS OF TIDAL STAGE--SEPTEMBER 1955

Chloride concentration was chosen as the quality constituent to represent salinity. Since data were available for only about 30 model junctions for the initial day of each simulation, initial concentrations were estimated for the remaining 800 junctions. In general the available chloride data represented concentrations at slack water following higher high water. Since slack water does not occur at the same instant in time throughout the system it was necessary to adjust these data to values which might have occurred simultaneously. These starting concentrations are extremely important in both simulations as they determine the mass of chloride in the system at the start of the run.

For both the July and September 1955 runs sufficient data were available to establish the maximum chloride concentrations at the seaward boundary. Other data [15] indicated the chloride fluctuation over the full tidal cycle. For both runs the simulation was completed in three steps: 1) a short initial run to assure proper starting conditions, 2) a longer run with a given set of boundary conditions representing the first part of the month, and 3) a final run with a different set of boundary conditions representing the last part of the month. This segmentation of each run was desirable since the prototype chloride level at the boundary increased during July 1955 and decreased during September 1955. This segmented approach made it possible to make appropriate changes in concentrations of other inputs, such as the inflowing streams. Initial chloride concentrations at the boundary for July and September 1955 are illustrated in Figure 7. After the first 27 days of the July simulation, the curve representing the boundary input was incremented upward by 2250 mg/l, while the September boundary concentrations were incremented downward 890 mg/l after the first 15 days.

Chloride concentrations in the tributary streams were obtained from published data [16]. Similarly, chloride concentrations in municipal and industrial waste water discharges were available [12, 13, 14, 15]. Data for total dissolved solids (TDS) levels in the agricultural drainage water were converted to chloride concentrations using appropriate TDS/chloride ratios [17].

Comparisons of model predictions and prototype behavior, at stations indicated in Figure 8, are illustrated in Figures 9 to 11 for the July 1955 simulation and in Figures 12 to 14 for the September 1955 chloride simulation. The model results are the maximum concentrations predicted for each day while the prototype concentrations were measured at slack water following the higher high stage of the tide, except as noted.

The agreement between model predictions and prototype observations is apparent. In several instances poor initial concentrations contributed to a slight discrepancy throughout the month. It is obvious from these figures that the prototype concentrations fluctuate considerably at most stations. This is caused in part by the continual change in tidal conditions over the lunar month. The difference between any two

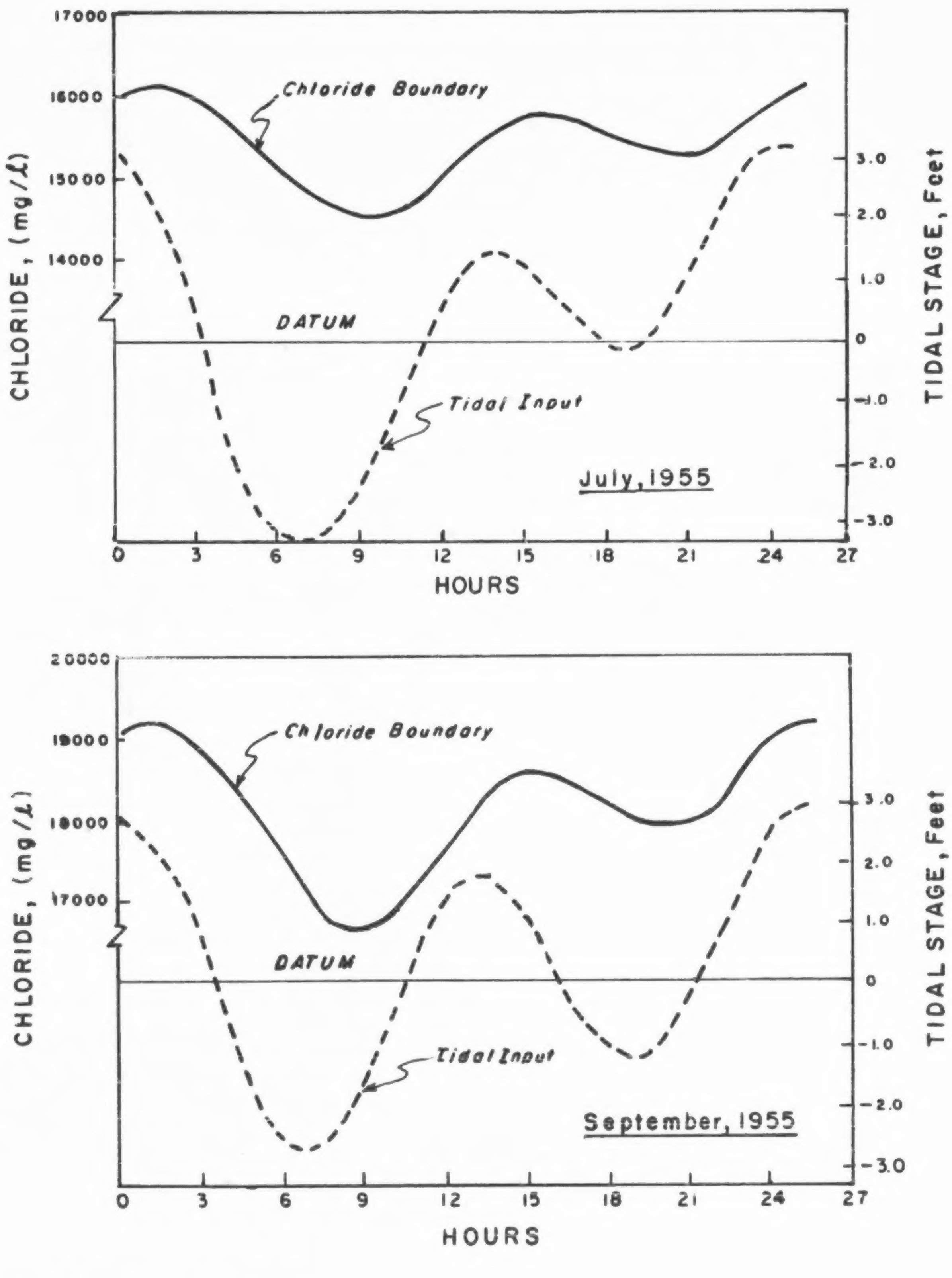


FIGURE 7. SPECIFIED BOUNDARY CONDITIONS--JULY AND SEPTEMBER 1955 CHLORIDE IN SAN FRANCISCO BAY-DELTA

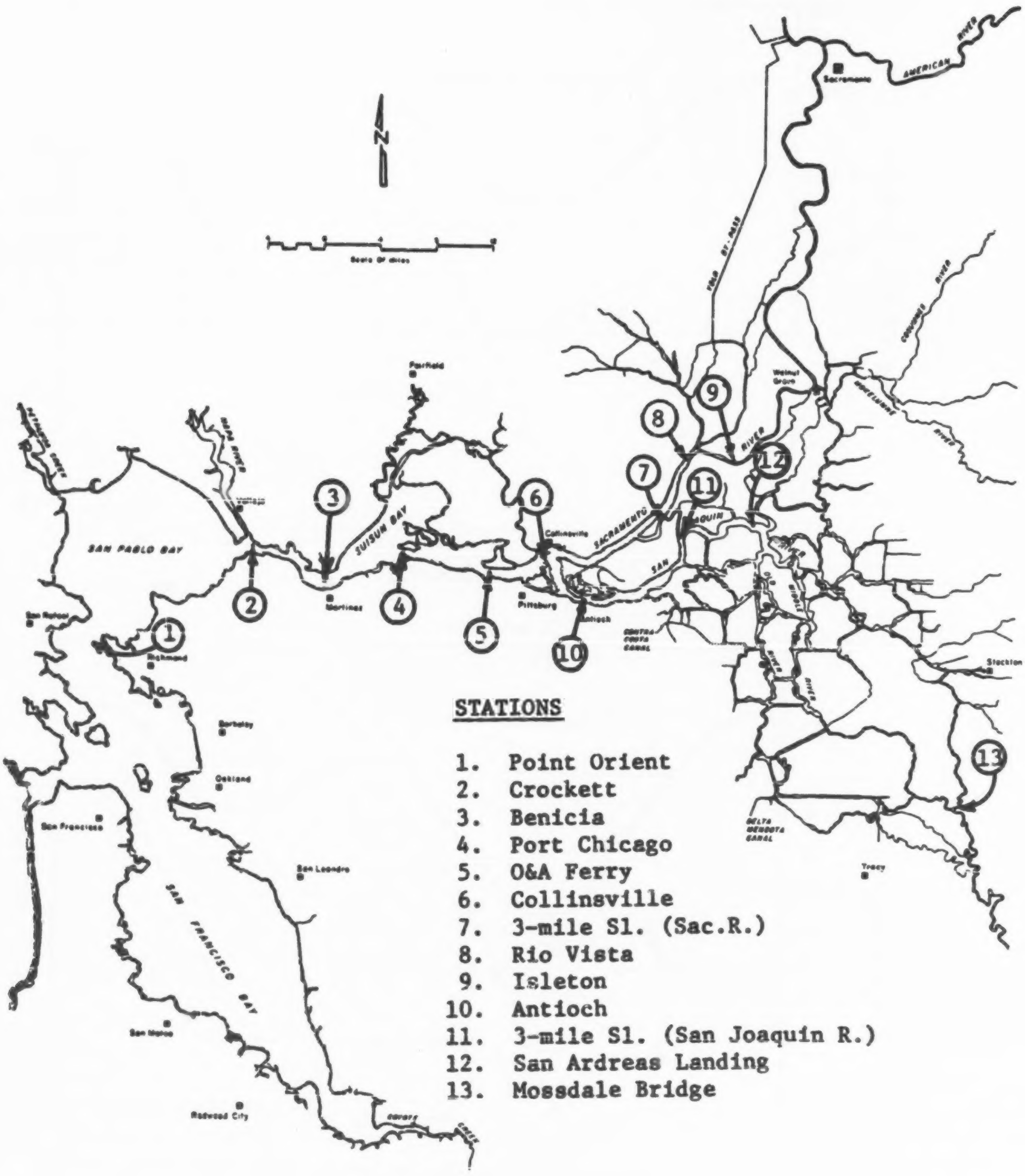


FIGURE 8. SAN FRANCISCO BAY-DELTA--COMPARISON STATIONS

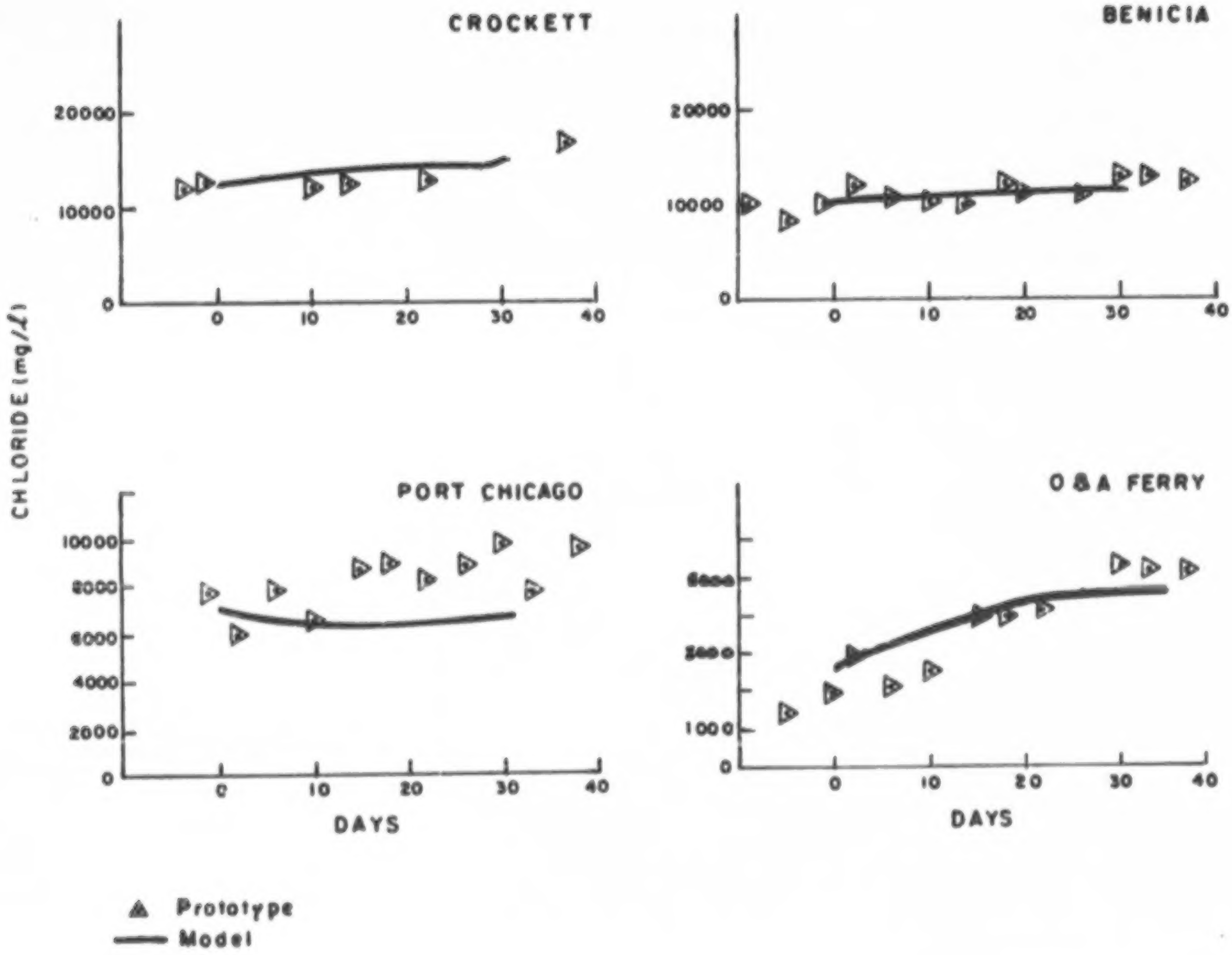


FIGURE 9. JULY 1955 CHLORIDE CONCENTRATION HISTORIES -- SAN PABLO AND SUISUN BAY STATIONS

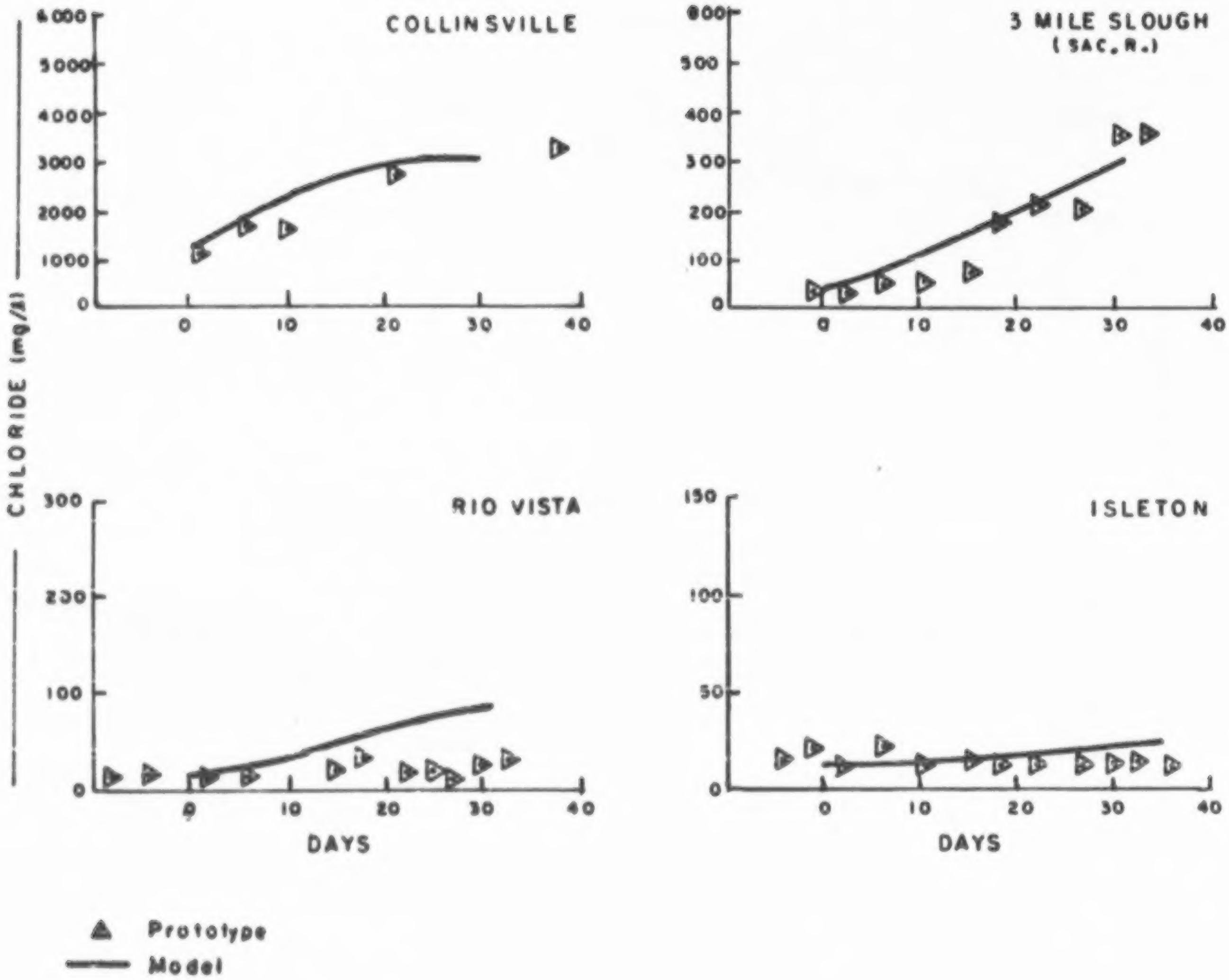


FIGURE 10. JULY 1955 CHLORIDE CONCENTRATION HISTORIES -- SACRAMENTO RIVER STATIONS

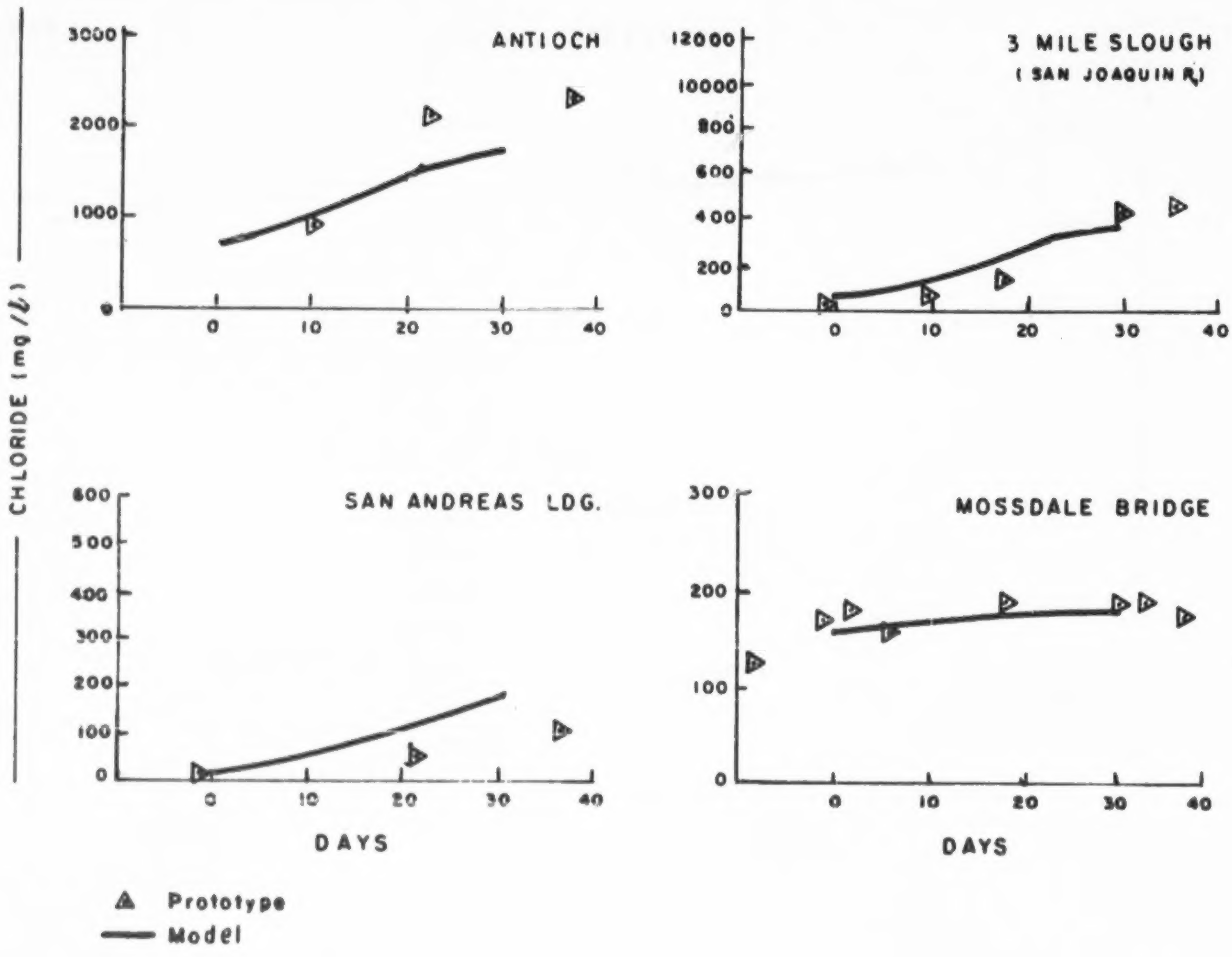


FIGURE 11. JULY 1955 CHLORIDE CONCENTRATION HISTORIES -- SAN JOAQUIN RIVER STATIONS

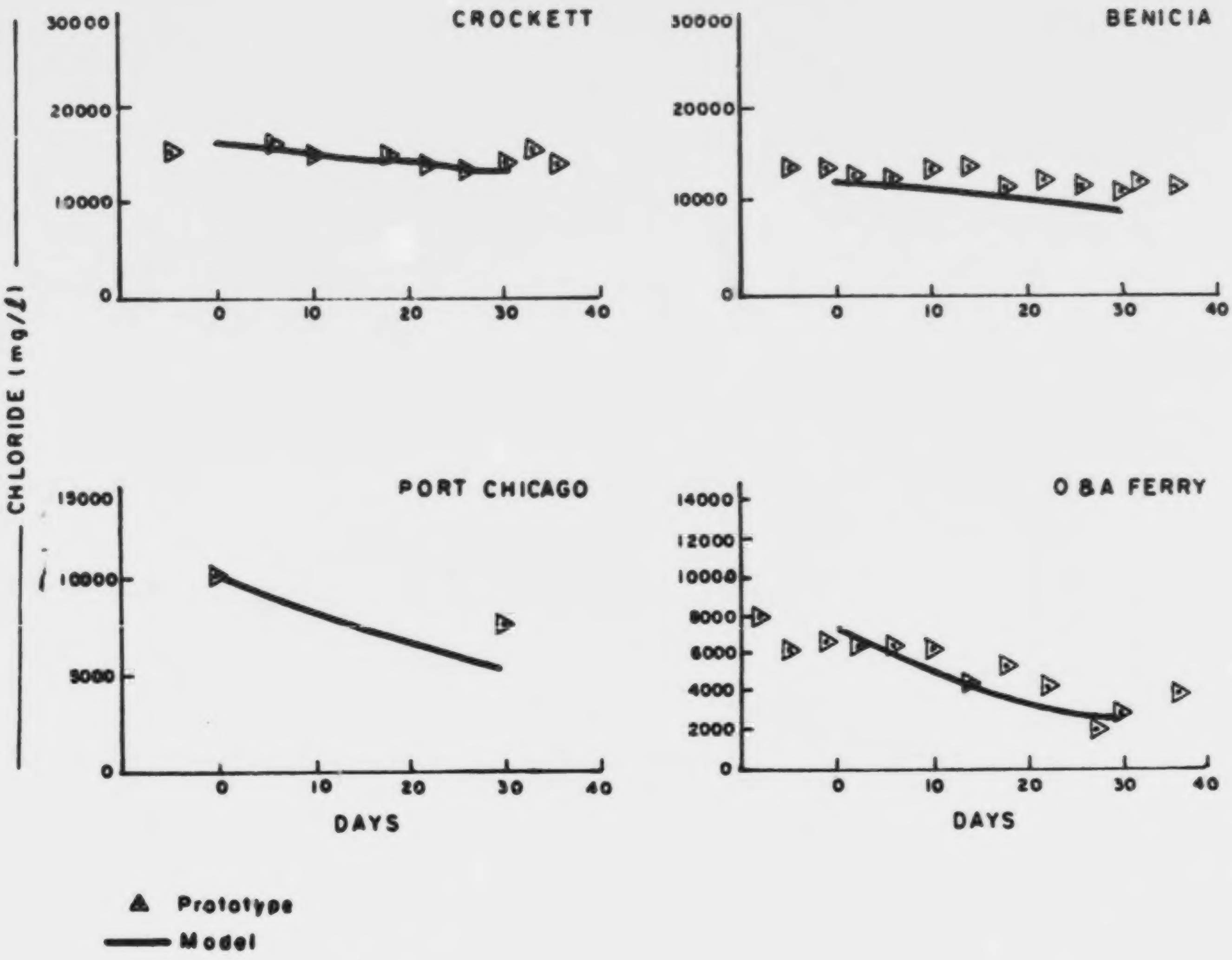


FIGURE 12. SEPTEMBER 1955 CHLORIDE CONCENTRATION HISTORIES -- SAN PABLO AND SUISUN BAY STATIONS

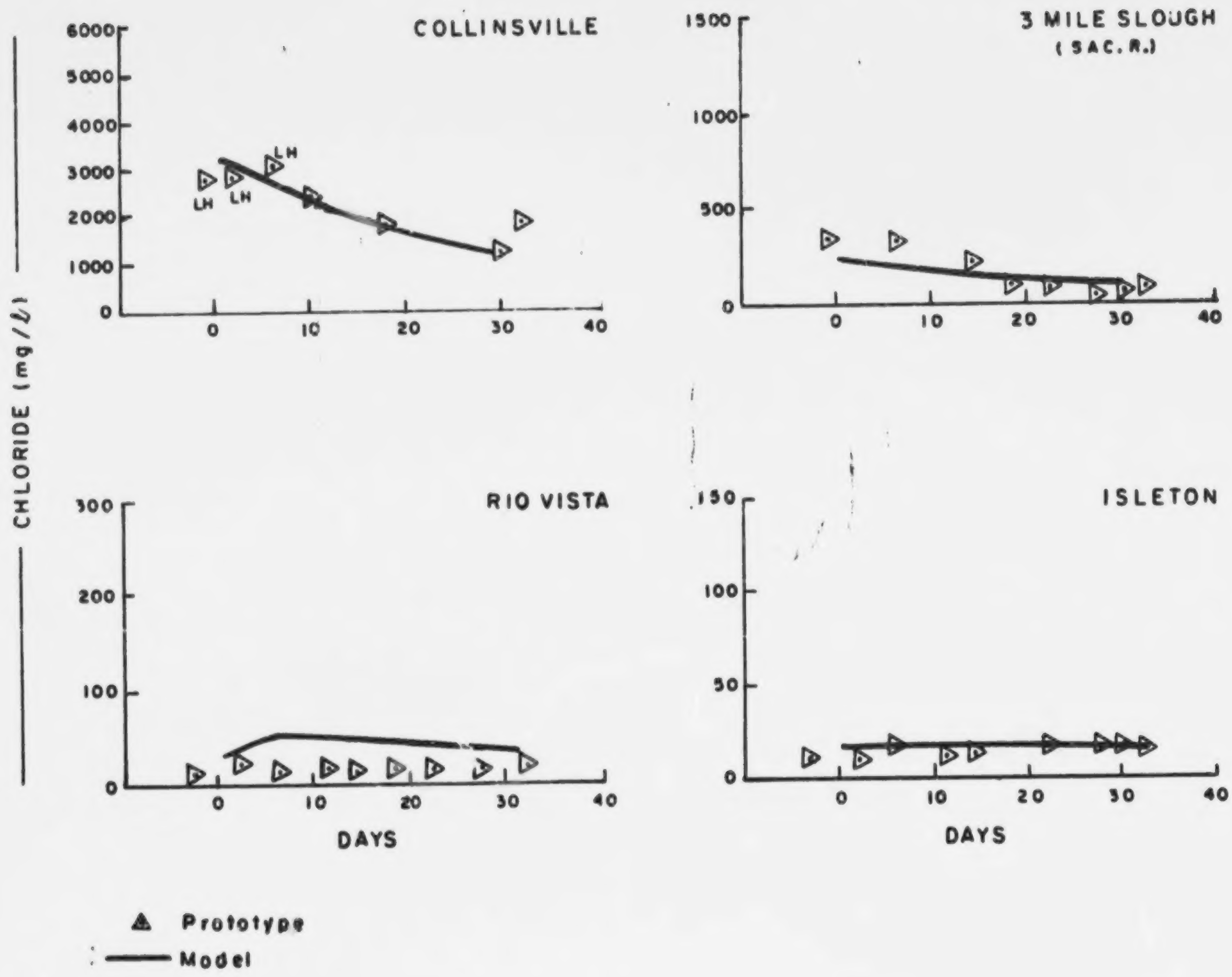


FIGURE 13. SEPTEMBER 1955 CHLORIDE CONCENTRATION HISTORIES -- SACRAMENTO RIVER STATIONS

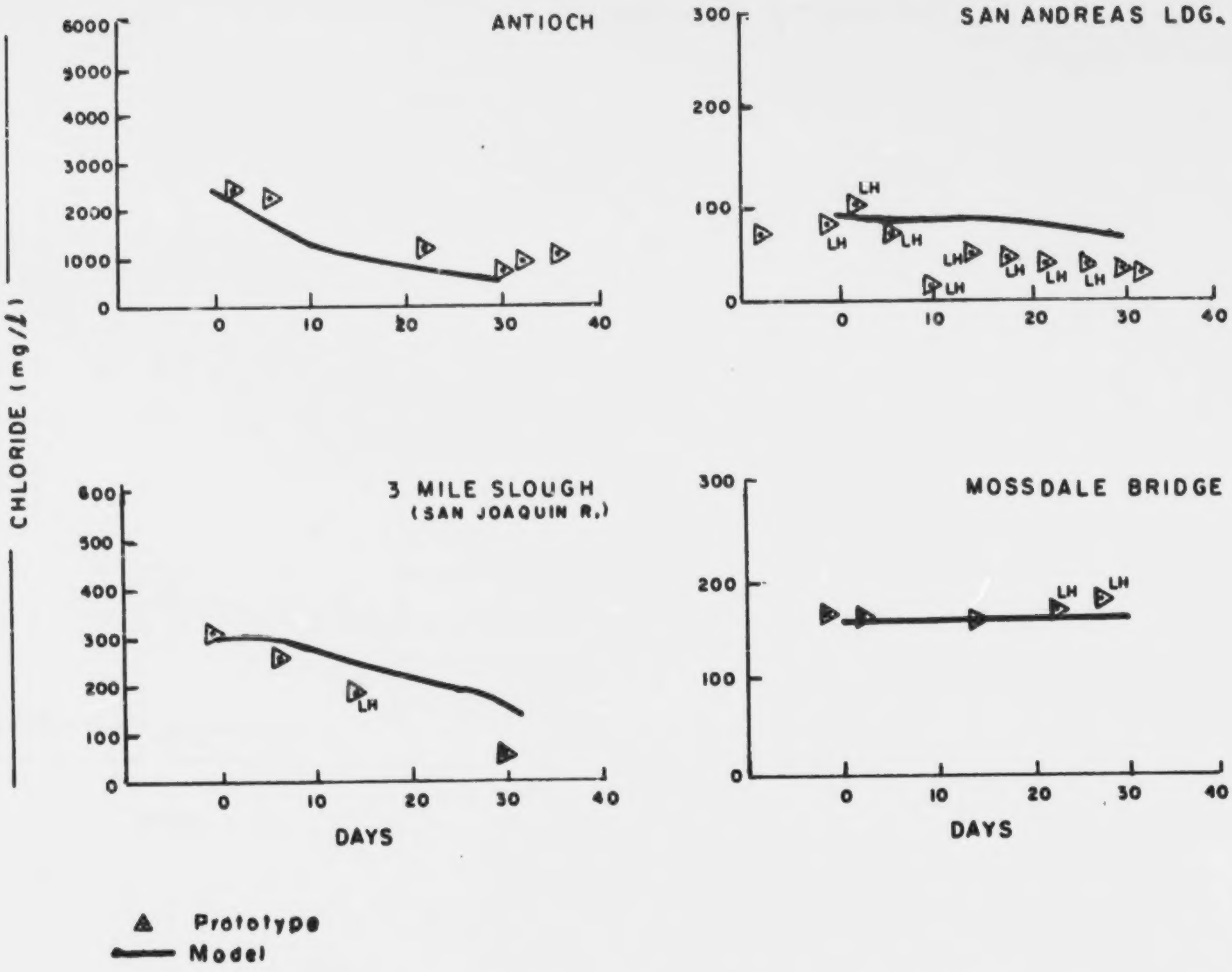


FIGURE 14. SEPTEMBER 1955 CHLORIDE CONCENTRATION HISTORIES -- SAN JOAQUIN RIVER STATIONS

consecutive maximum concentrations at a given point is significantly dependent on the difference in tidal excursions on the days the samples were taken. Thus even though the overall trend is upward during July, there are short-term downward trends at many stations. Because the model uses a constant average tidal condition the model predictions do not follow these irregular trends. The changes in concentration predicted by the model generally follow smooth curves.

The most apparent discrepancies between model predictions and prototype behavior are at Antioch, Rio Vista, and Port Chicago for the July simulation and at Three-mile Slough (San Joaquin River), Rio Vista, San Andreas Landing, and Port Chicago for the September run. With the exception of the Antioch and Port Chicago stations the model predictions are somewhat higher than prototype observations. It is noteworthy that the discrepancies (with the exception of Port Chicago) occur at stations which are near the salinity front where the salinity gradient is very steep. A slight horizontal displacement of the gradient can result in a significant change in concentration at such points. It is at such stations that comparison between model predictions and prototype observations is difficult in that the prototype observations fluctuate in accordance with differences in tidal excursion distances from day to day and any given observation may or may not be indicative of the general trend at the point. There is also the problem of correlating the actual sampling points in the prototype with junctions in the model network. Since the model network was generally dictated by geometric considerations (or, as previously discussed, by the computational stability criterion) the junction locations do not necessarily coincide with sampling stations in the prototype. In addition a sampling station may be located at a particular point because it is convenient for sample collection. Samples collected at such a point usually won't be representative of the entire cross-section at that point. The model prediction for a point, on the other hand, represents the mean concentration of the completely mixed volume of the network junction.

The underlying cause of the discrepancies at the Port Chicago station is not known with any certainty. Improper initial conditions for much of Susuin Bay may be responsible. For example, it can be noted in the July comparison that the model predictions decreased during the initial ten days and then increased through the remainder of the month, a phenomenon that could result from an improper initial chloride distribution in the embayment portions of Suisun Bay.

For studies such as these, wherein historic conditions are being simulated, the specification of starting concentrations for the initial day of the simulation can present significant problems. For the July and September runs prototype observations were available for only a very limited number of stations in the system and for a specific tidal stage (generally at higher high slack water). From these extremely limited data the initial chloride distribution for the entire system was estimated. Since only a small area of the estuary is at higher high slack water at any instant it was necessary to adjust the slack water observations at most stations to the tidal phase which would exist at that point at the start of the simulation. The problem was thus one of estimating the initial conditions for the entire system such that the higher high slack water concentrations predicted by the model during the initial day of the simulation matched the observed prototype concentrations for the initial day of the period. Even if this criterion is satisfied there is no real assurance that the starting concentrations are correct since there are large areas for which no comparison is possible. Although the initial conditions specified in areas far removed from the comparison stations have little effect on the model predictions for the initial day of the simulation they may have significant effects later. This is illustrated in Figures 15 and 16 wherein the July and September 1955 chloride simulations are compared for two different sets of starting concentrations. For both the July and September runs the starting concentrations originally specified (labeled model #1) were adjusted and the simulation repeated (labeled #2). Generally the adjustments were confined to areas near stations at which the above criterion was not met (i.e., where the predicted maximum concentration for the first day of the simulation did not match the observed prototype value). Other adjustments were made in the embayment portions of Suisun Bay and in areas of the Delta wherein no prototype data were available since it was in such areas that the original chloride distribution was specified with the least confidence. The adjustments were relatively minor and the resulting chloride distribution was considered as probable as the original.

Significant differences in model predictions at several stations are noted for both months. For the July runs the predictions for the rerun more closely match prototype behavior (with the exception of the Autioch station). The rerun for September resulted in improvements at some stations but inferior predictions at others. The predictions could probably be further improved at many stations with additional refinement of the initial conditions.

In light of the many problems associated with comparisons of model and prototype behavior discussed above, the July 1955 and September 1955 chloride runs were considered satisfactory verification of the model's ability to simulate salinity incursion and repulsion.

Tracer Release Simulation. In the fall of 1966 the (then) FWPCA Central Pacific Basins Project conducted a field study of the dispersion characteristics of Suisun Bay and the western Delta. Primary purposes were to investigate the fate of agricultural waste water consituents which might be discharged near the Antioch Bridge by the proposed San Joaquin Valley Drain and to develop data for model verification purposes. The study was designed to determine both the rate of increase in tracer concentration at various locations within the study area resulting from discharge of tracer over an extended period, and the concentration which would be attained at steady state. The California Department of Water Resources cooperated in this study.

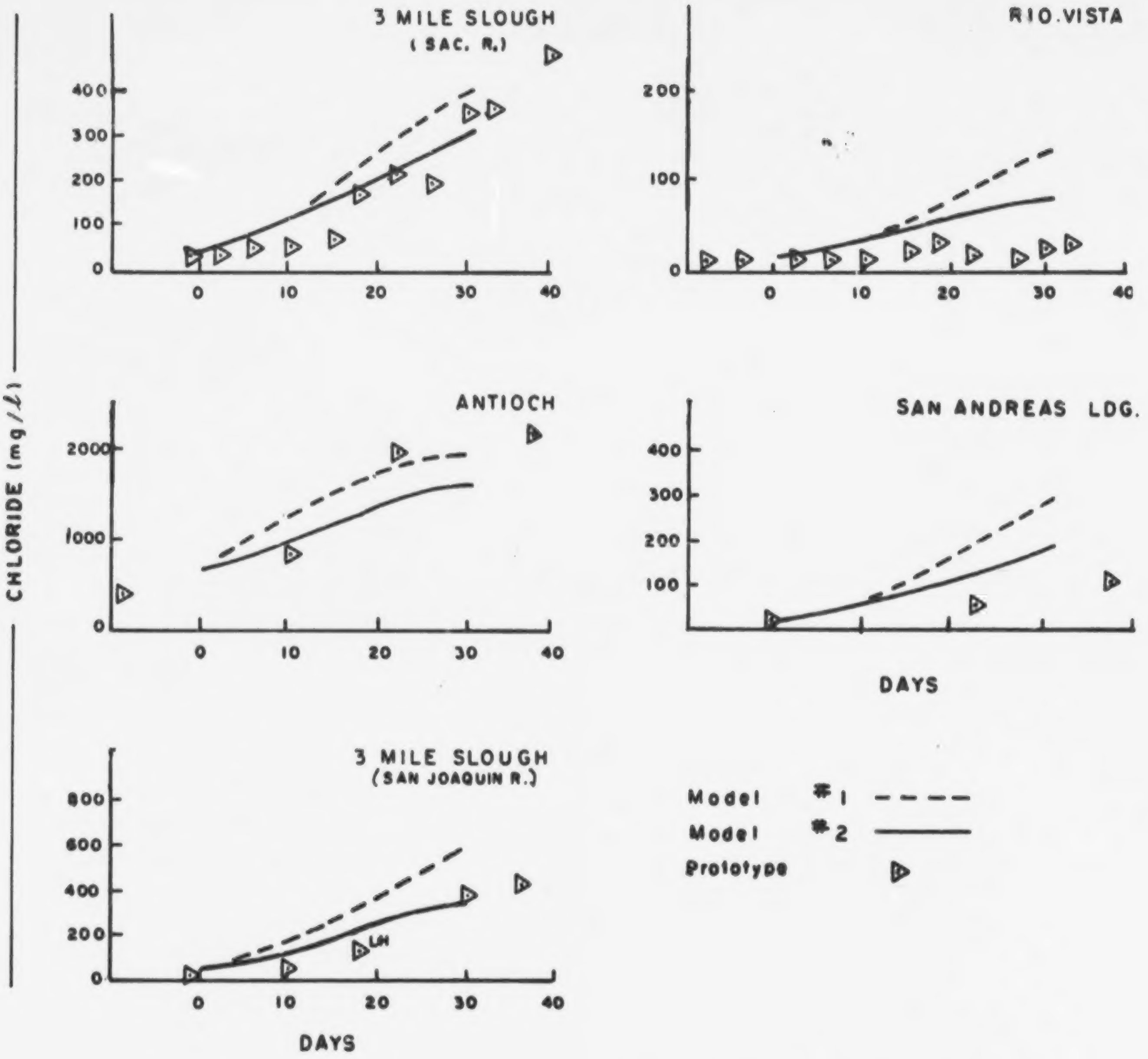


FIGURE 15. EFFECT OF INITIAL CONDITIONS ON MODEL PREDICTIONS -- JULY 1955 CHLORIDE

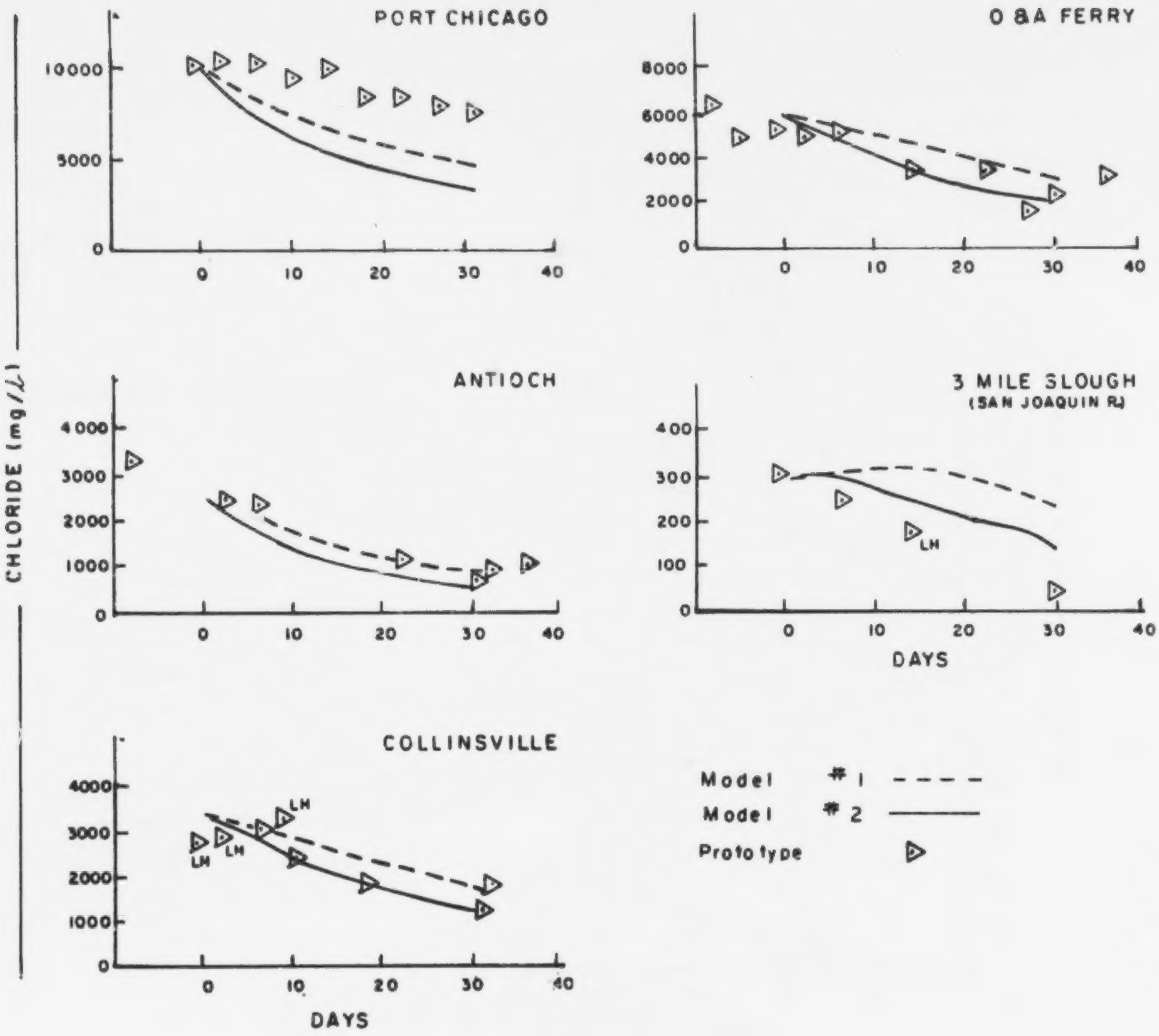


FIGURE 16. EFFECT OF INITIAL CONDITIONS ON MODEL PREDICTIONS -- SEPTEMBER 1955 CHLORIDE

Experience with the mathematical model and the Corps of Engineers Bay Model indicated a minimum of three weeks release was necessary to build up tracer concentrations to the point where they could be extrapolated to steady state concentrations. The release period was scheduled from HHWS on September 20, 1966 at 2232 PDT to HHWS on October 12 at 0420 PDT, a total of 21 days, 5 hours, and 48 minutes. Using an 18 barrel supply, the discharge rate would be 56.1 ml/min.

The tracer was released at the Antioch Bridge pier from 55 gallon drums equipped with constant flow rate devices. When used with airtight, rigid wall drums, these devices maintain a balance between atmospheric pressure and the negative pressure within the drum such as to produce a constant flow rate despite the changing depth of liquid in the drum. By using two 55 gallon drums it was possible to maintain an almost uninterrupted flow while replenishing the dye supply from the manufacturer's plastic barrels. The discharge point was about three feet below the water surface at mean lower low tide. The actual flow rate was monitored on both daily and instantaneous bases. An estimate of the daily rate was made from the frequency with which the 55 gallon discharge drum was filled. The daily rate of discharge was approximately constant at an average of 0.85 barrels a day. Measurements of instantaneous flow rates with a graduated cylinder indicated a diurnal fluctuation of up to 50 percent above or below the average flow rate.

During the first 18 days and 10 hours of the study, a total of 15.5 drums of dye, at 250 lbs. apiece, was discharged. This averaged 55.9 ml/min for the period, as compared with the 56.1 ml/min flow rate calculated prior to the test. On the 19th day of the release a complete stoppage of undetermined cause occurred, which lasted 10 hours before being detected. For the remainder of the release period, or 2 days and 11 hours, an average rate of 50.1 ml/min was maintained. This represented an additional 2.9 barrels, making a total of 17.4 barrels of dye discharged to the system.

Tracer concentrations were observed in the principal channels at slack water using G. K. Turner Model III Fluorometers mounted in two boats. Continuous records were obtained from Fluorometers at the Antioch Bridge and the Contra Costa Canal Pumping Plant intake. After the discharge of tracer was stopped on the 21st day, measurement of tracer concentration continued with lesser sampling frequency for about five weeks, at which time the observed concentrations were little above background. The study area in which the movement of tracer was monitored is shown in Figure 17.

If the rate of tracer injection, tidal dispersion characteristics, net advective flow, length of the tidal excursions and system geometry were all constant, the concentrations measured at the same stage of the tide at a given station would produce a smooth cumulative concentration history. This result is obtained with the usual mathematical or physical model. In the prototype study, however, only the dye injection rate, the geometry of the system, and the distance from the release

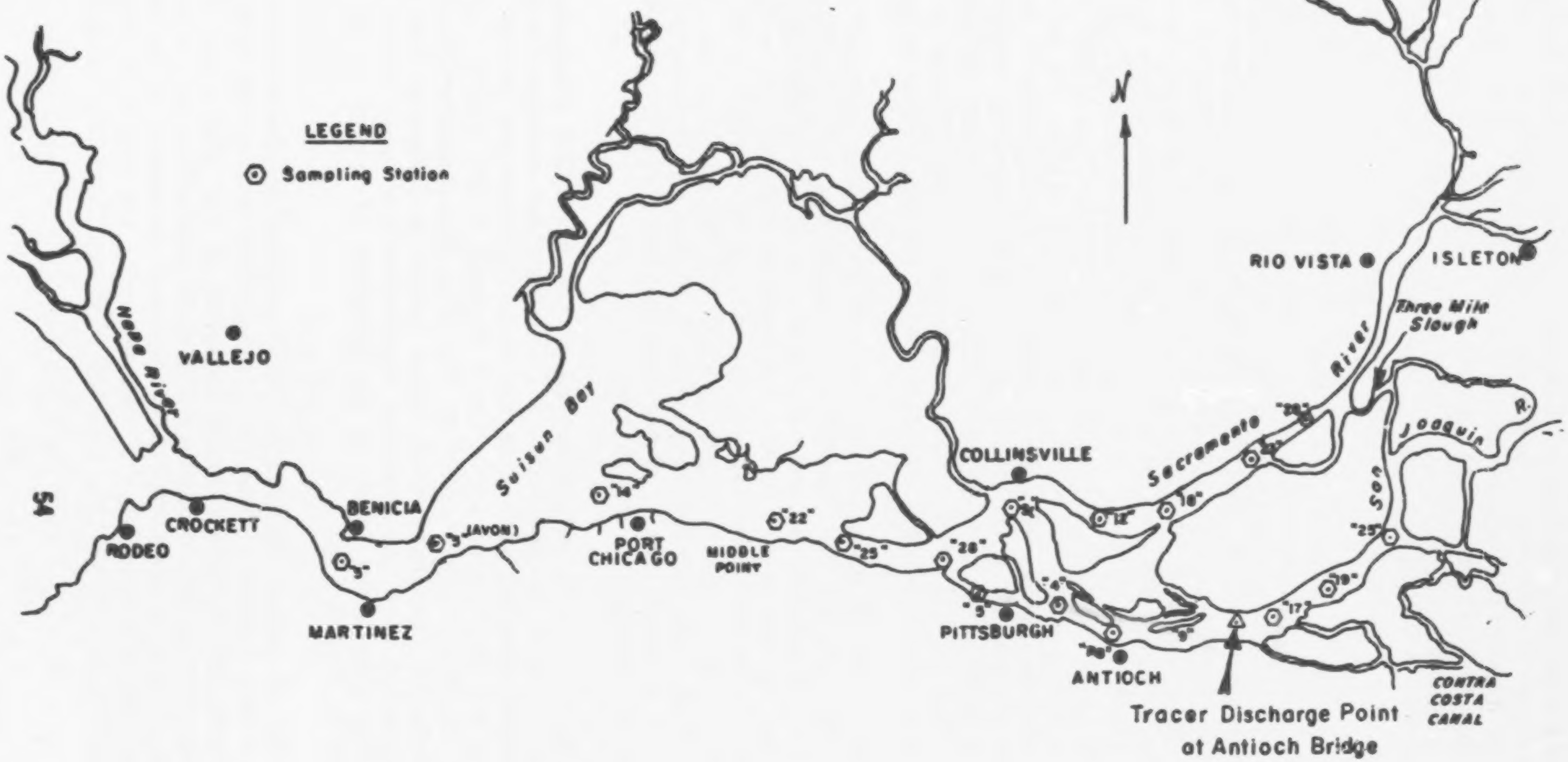


FIGURE 17. STUDY AREA WITH TRACER SAMPLING STATIONS -- SAN FRANCISCO BAY — DELTA

point to the observation station were constant. The hydrodynamics and hence the dispersion processes at each station were continually changing in response to variable tidal excursion distances, fluctuations in fresh water inflow, and progressive transitions in tidal stages. The result was somewhat unordered station histories and longitudinal profiles. The section of the study area in which the most erratic station concentration histories occurred lay within an average excursion distance up and downstream from the release point at the Antioch Bridge. Beyond an excursion distance the observed station histories more closely approach the idealized concentration histories.

The continuous, point discharge of dye resulted in local areas of high concentration near the release point at slack water. The areal extent was such that high concentrations were observed frequently at the intake of the Fluorometer mounted on the Antioch Bridge, at a distance of about 200 feet. However, after the next running of the tide the dispersion of this patch of high concentration was such that no tracer peak was observed at the next slack. Such peaks apparently do not survive the dispersion effects during the tidal excursions but instead reinforce a single cumulative peak. The longitudinal profiles show slight irregularities superimposed on this cumulative peak but it was not possible to identify these as the result of specific slack periods.

The observed concentrations near the release point at the Antioch Bridge are presented in Figure 18. High concentrations associated with the spread of tracer at slack water have been excluded. Also shown are the concentrations computed by the mathematical model as will be discussed subsequently. The erratic variations in prototype concentration should be noted. As would be expected concentrations tend to increase during the period that tracer was discharged but decrease rapidly after the tracer was stopped on the 21st day. The maximum concentrations on the 17th day were observed between LH and HL tides, which corresponds to the shortest excursion during the release period.

The concentration histories for several locations in Suisun Bay and the western Delta beyond a tidal excursion distance from the release point are presented in Figures 19 to 21. Concentration profiles along the ship channel in Suisun Bay on the 19th and 20th days of the tracer release period are presented in Figure 22. Included on these figures are the concentrations predicted by the mathematical model as discussed below.

The mathematical model was used to predict the concentration histories resulting from the introduction of a tracer under the conditions experienced in the prototype study discussed above. The model was applied consecutively as follows:

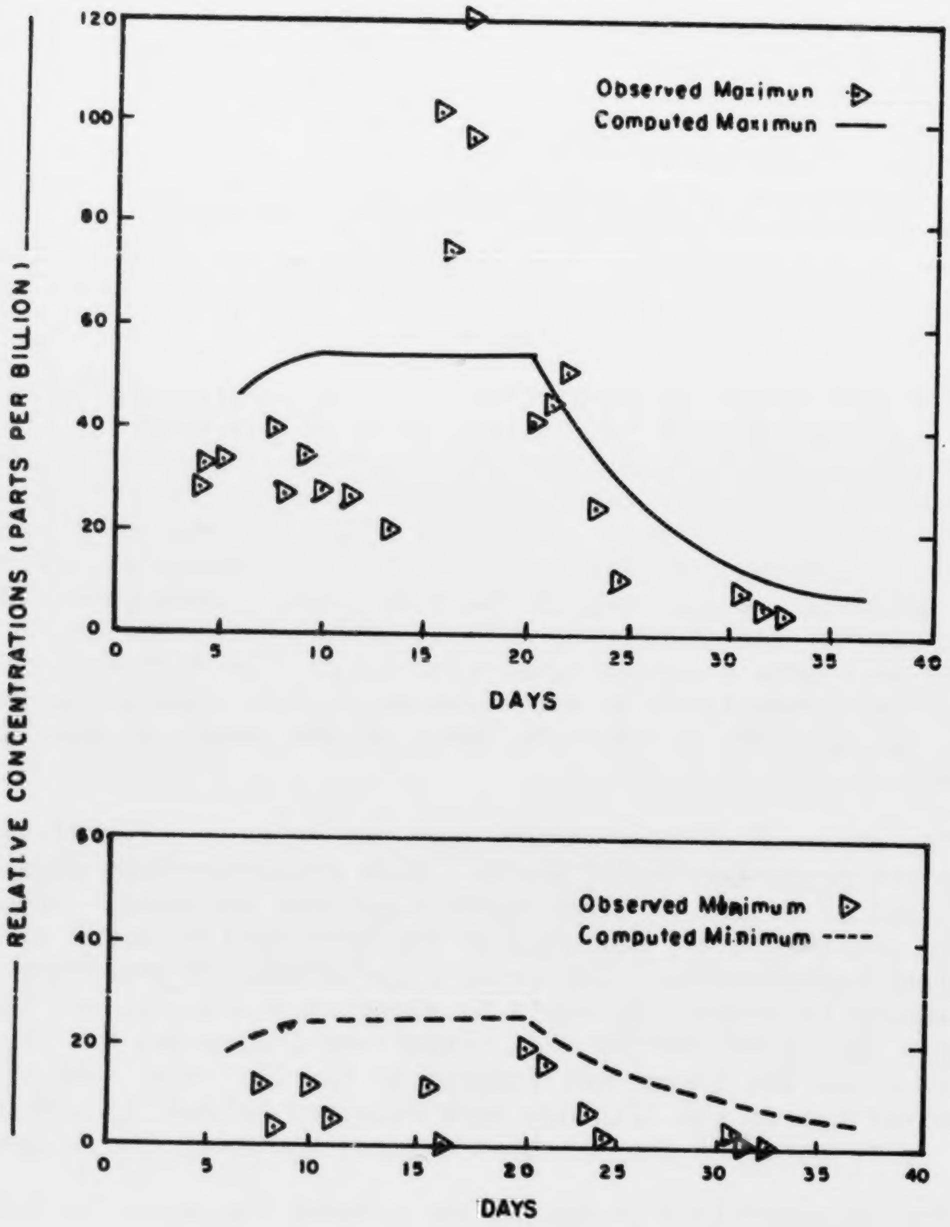


FIGURE 18. OBSERVED AND COMPUTED MAXIMUM AND MINIMUM TRACER CONCENTRATIONS AT ANTIOCH BRIDGE

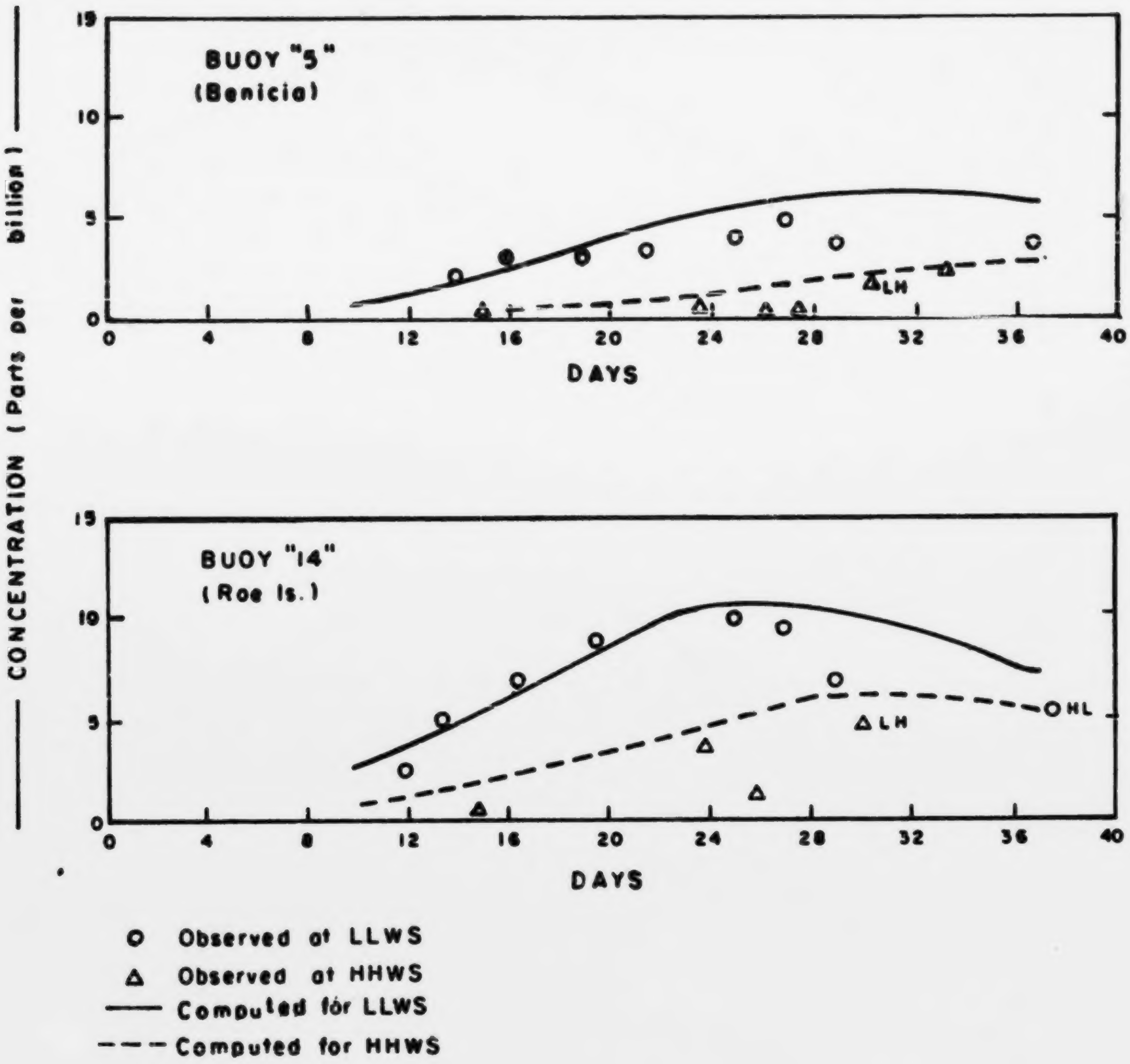


FIGURE 19. TRACER CONCENTRATION HISTORIES AT SELECTED STATIONS IN SUISUN BAY

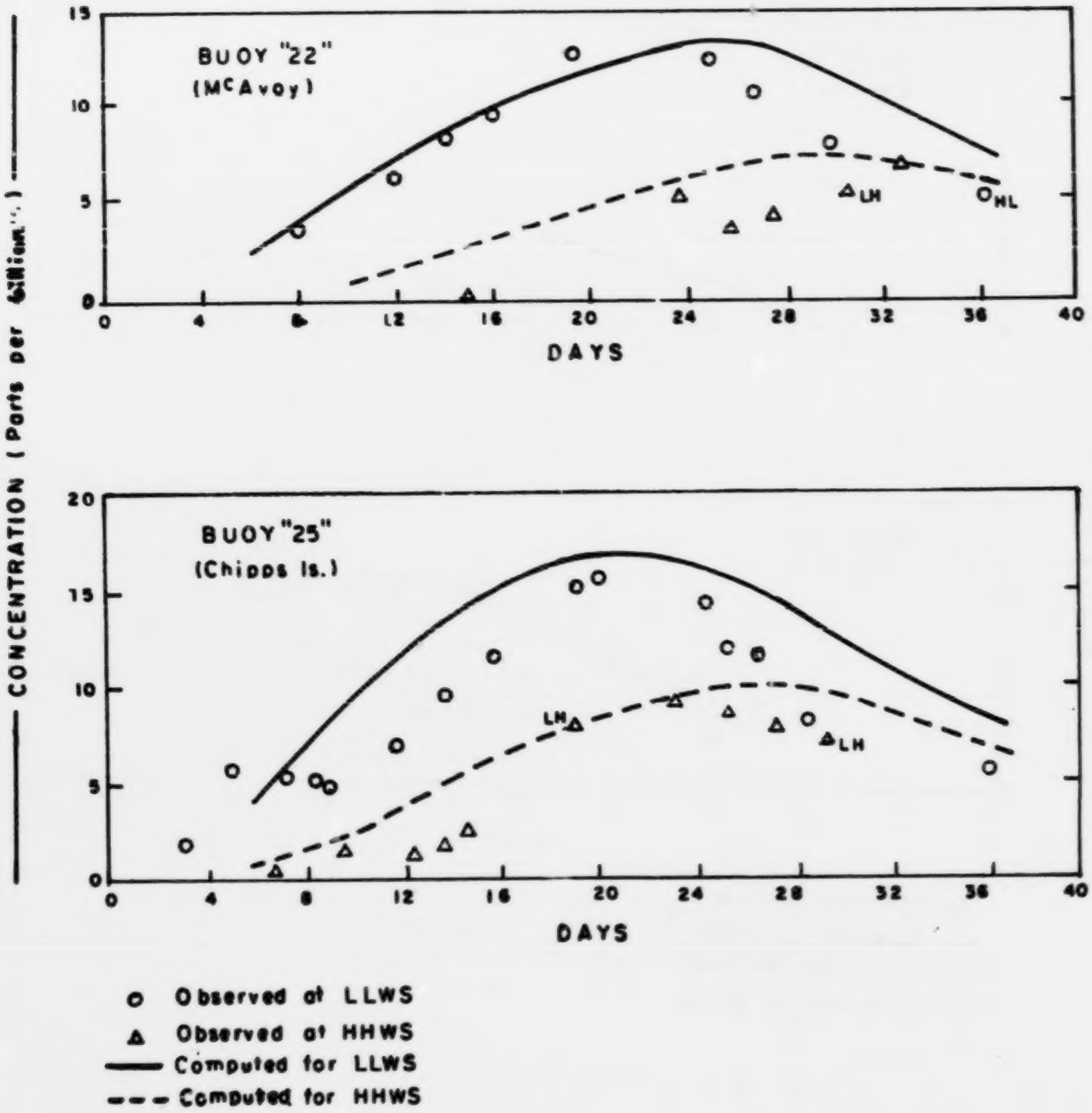


FIGURE 20. TRACER CONCENTRATION HISTORIES AT SELECTED STATIONS IN SUISUN BAY

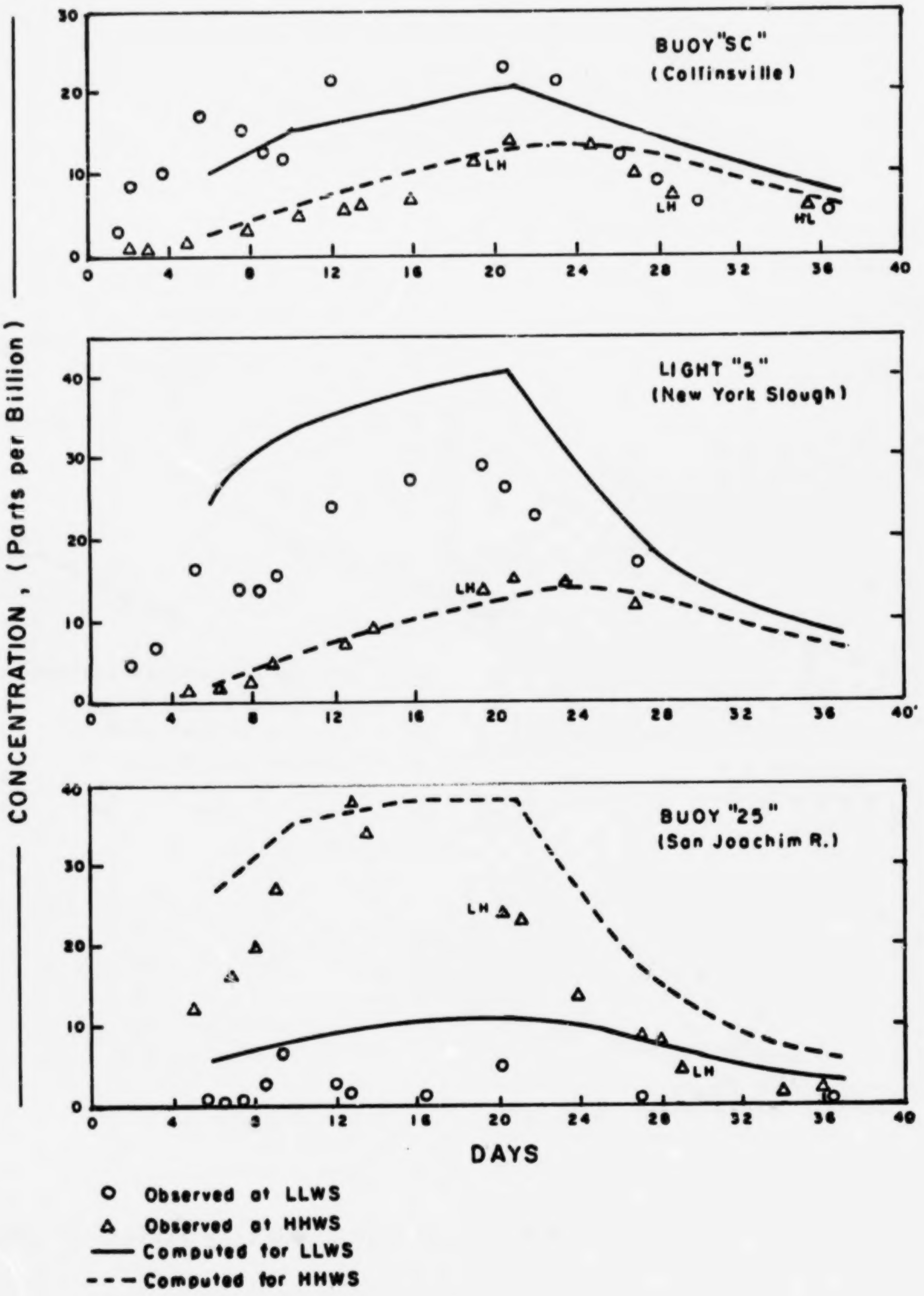


FIGURE 21. TRACER CONCENTRATION HISTORIES AT SELECTED STATIONS IN WESTERN DELTA

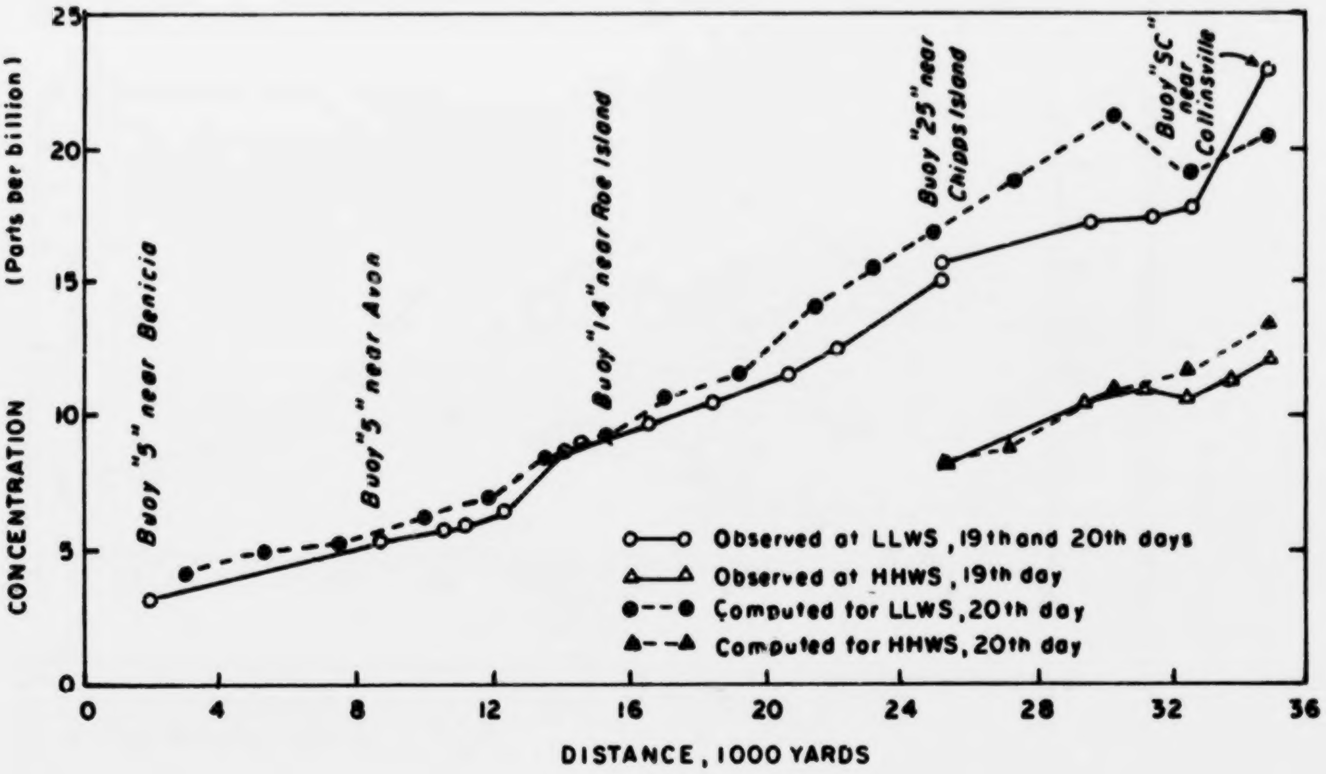


FIGURE 22. TRACER CONCENTRATION IN SHIP CHANNEL -- BENICIA TO COLLINSVILLE

1. Ten days of tracer addition with mean September hydraulic conditions.

2. Eleven more days of tracer addition with mean October hydraulic conditions.

3. Twenty-one more days with mean October hydraulic conditions without addition of tracer.

Hydraulic input was based primarily upon measured inflow to the Delta, estimated Delta consumptive use, and typical municipal and industrial waste discharge rates. A tracer loss rate of 3.4 percent per day was assumed based upon a previous study under estuarine conditions [20].

The predicted tracer concentrations together with the prototype observations were presented in Figures 18 to 22. The prototype concentrations were observed at slack water following the higher high and lower low tidal stages except as noted in the figures. The background fluorescence, determined prior to the tracer release, was subtracted from observed prototype concentrations.

The model predictions presented are the maximums and minimums over the tidal cycle and do not necessarily correspond to slack water conditions since, at points within a tidal excursion up and downstream from the release point, the maximum and minimum concentrations do not necessarily occur at slack water.

Figures 18 through 21 indicate generally good agreement between model predictions and prototype observations. At most stations good agreement was obtained for both higher high water slack (HHWS) and lower low water slack (LLWS) conditions. Figure 22 indicates the model prediction of the longitudinal distributions of tracer in the main channel of the system closely matches that observed in the prototype with agreement generally improving with distance from the release point. This is expected since the concentration gradients are generally most pronounced near the release point and the observed slack water concentrations at a station are strongly influenced by the varying tidal excursion distances from day-to-day. At stations farther removed from the release point where concentration gradients are relatively flat the tidal effects are much less pronounced.

In some instances the prototype observation stations do not coincide with model prediction points (network nodes). In such cases the network node nearest to the prototype observation station was used. In areas with pronounced concentration gradients the model predictions at such stations may be consistently biased either upward or downward. This problem is illustrated in Figure 23 which indicates the position of a prototype station (Buoy 22) relative to the three nearest network nodes and compares the model predictions for the three nodes with the prototype observations.

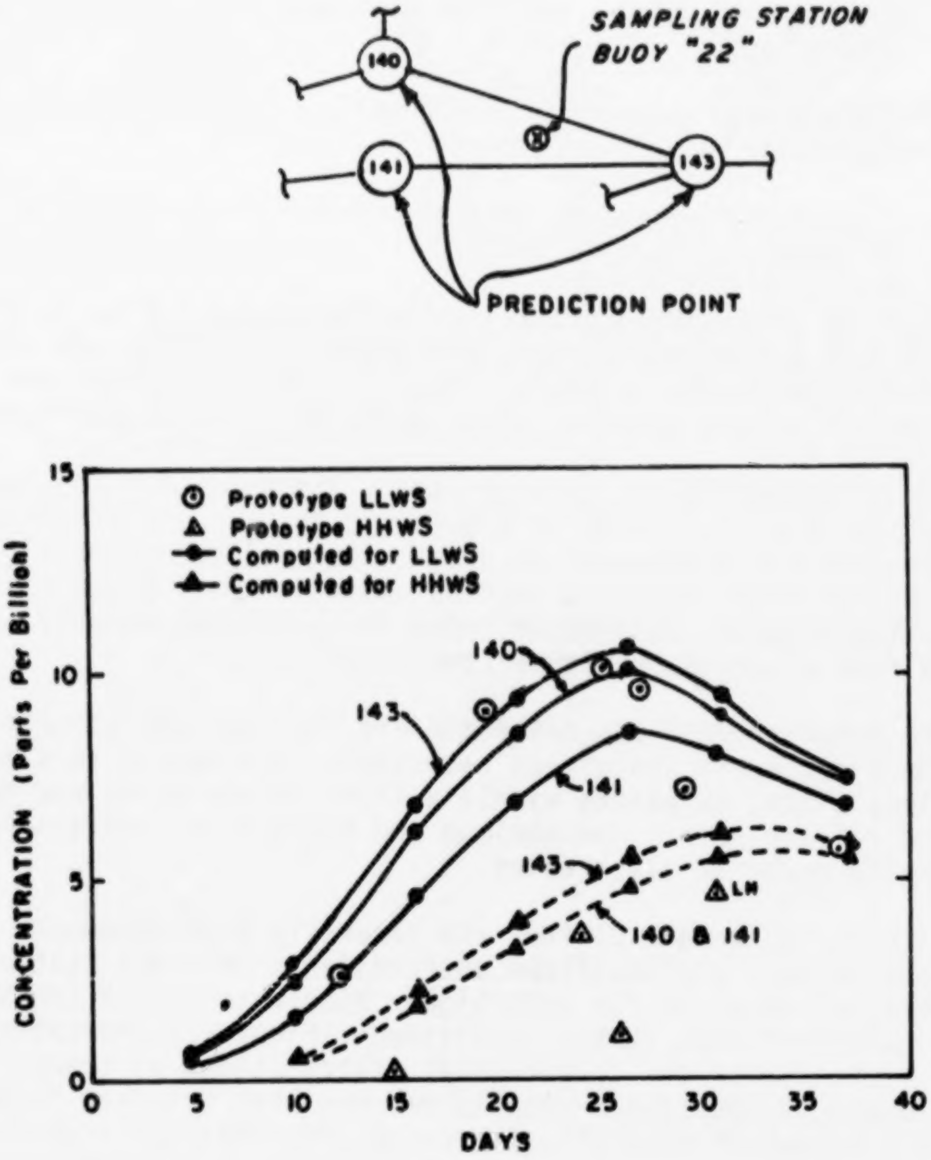


FIGURE 23. ILLUSTRATION OF COMPARISON DIFFICULTIES DUE TO NONCORRESPONDENCE OF OBSERVATION AND PREDICTION POINTS

As indicated earlier two different hydraulic conditions were utilized for the model simulation. Although the measured inflows and pumped exportations remained relatively constant throughout the study period, other hydraulic losses such as evaporation and agricultural consumptive use were undoubtedly decreasing through the period. The net outflow from the system would correspondingly increase under such circumstances and increase the rate of flushing from the system. This would not be reflected in the model predictions since the hydraulic conditions utilized by the model remained constant throughout the last eleven days of the tracer release period and the entire twenty-one days of the washout period (following the tracer shutoff).

The effect of the hydraulic conditions on the model predictions can be noted in Figures 18 through 21. The net outflow (past Chipps Island) was increased approximately fifteen percent (from 5540 cfs) following the initial ten days of the release. There is little apparent effect at the stations in Suisun Bay but at stations in the western Delta the rate of buildup of tracer during the initial ten days of the release period is significantly different than that during the next eleven days. This may indicate the effects are attributable more to the balance of flows between the Sacramento and San Joaquin Rivers for the two parts of the simulation than to the combined net increase in outlow. The stations not apparently affected are in Suisin Bay, downstream from the confluence of the two rivers.

Most of the increase in outflow resulted from a 51 percent increase in the net downstream flow of the San Joaquin River (from 1372 cfs) with only a minor increase (two percent) in the net downstream flow in the Sacramento River. The stations most affected are Buoy "25" on the San Joaquin River, Buoy "SC" at the confluence of the two rivers, and the station near the release point at Antioch Bridge on the San Joaquin.

Another factor which may affect the comparison is the tracer loss rate utilized for the simulation. As indicated previously the loss rate specified (3.4 percent per day) was determined from data gathered in a tracer study on the Potomac River in which a mass balance was maintained over a period of 20 days following the release. For that determination all tracer not detectable was assumed to contribute to the loss rate computed. This included tracer at a concentration below the lower limit of the detection instrument; therefore the computed rate was undoubtedly somewhat above the actual loss rate.

Limited laboratory studies by FWQA indicated an overall loss factor between one and two percent per day. This is consistent with estimates obtained from earlier experimental work with Rhodamine WT dye conducted by the Chesapeake Bay Institute [21].

The significance of the tracer loss rate specified for the model simulation is illustrated in Figure 24. The model simulation was conducted with two different decay rates, as indicated. Generally the utilization of the lower loss rate (1.7 percent per day) resulted in

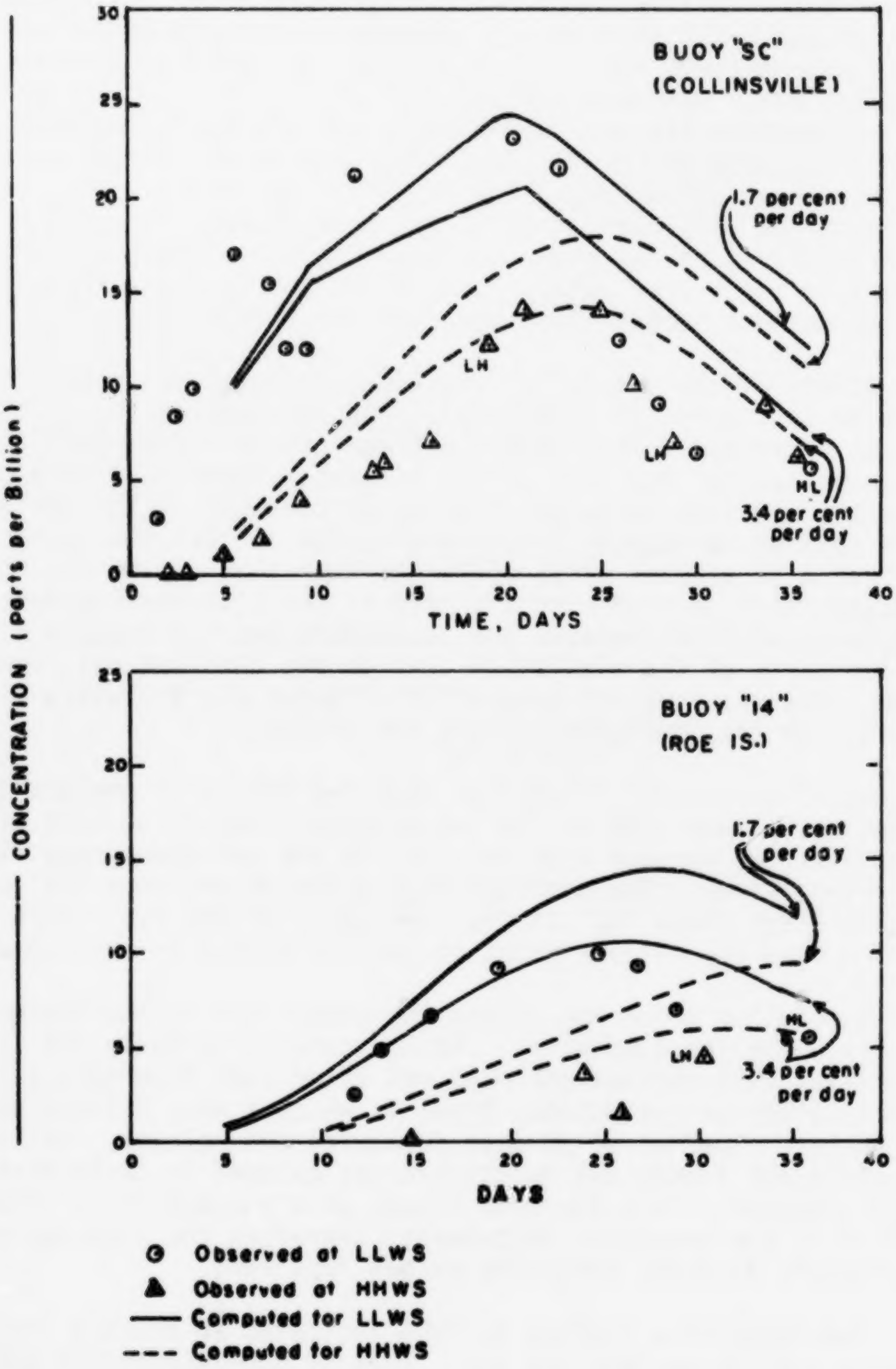


FIGURE 24. EFFECT OF SPECIFIED TRACER LOSS RATE ON MODEL PREDICTIONS -- SAN FRANCISCO BAY-DELTA

predictions above those observed in the prototype, particularly during the washout period of the study. Because of the aforementioned uncertainty of the prototype hydraulics during the latter part of the study it is difficult to evaluate whether such discrepancies are due more to the loss rate specified, the hydraulics of the system, or to the model structure. A discussion of the significance of other parameters (which are associated more with the model structure or general behavior rather than with a particular constituent or study) affecting model predictions is included in a later section.

In view of the many factors affecting and complicating a comparison of this type the agreement between model predictions and prototype behavior for this study is considered very good.

## SAN DIEGO BAY

The dynamic estuary model was applied to San Diego Bay by FWQA as part of the Vessel Pollution Study of San Diego Bay, California [5]. The model was utilized in this study to predict coliform distributions resulting from the U. S. Naval Fleet anchored in San Diego Bay. The Bay is illustrated in Figure 25.

San Diego Bay was characterized by a two-dimensional network of 112 junctions (nodes) connected by 170 channel elements (links). The entire Bay was modeled including the channel 1 1/2 miles seaward of Ballast Point.

### Hydraulic Verification

The ability of the model to simulate the hydraulic behavior of San Diego Bay was demonstrated by comparing the tidal stages at points within the Bay predicted by the model with those predicted using U. S. Coast and Geodetic Survey Tide Tables. For this study the tide imposed at the seaward boundary (Point Loma) was representative of a mean annual tidal condition in the Bay. Other significant hydraulic inputs included evaporation (78 cfs), which was distributed uniformly over the Bay, a diversion to the salt ponds in the South Bay (2.6 cfs), and a cooling water diversion and return (646 cfs). A Manning's roughness coefficient (n) of 0.018 was assumed for the entire Bay. The solution for dynamic equilibrium was obtained using a time step of 50 seconds.

The comparison of predictions at two points is presented in Figure 26 together with the specified tide imposed at Point Loma.

### Quality Verification

Few existing data were available on the distribution or dispersion of a water quality constituent through San Diego Bay. To help define the dispersion characteristics of the Bay and to provide data for use

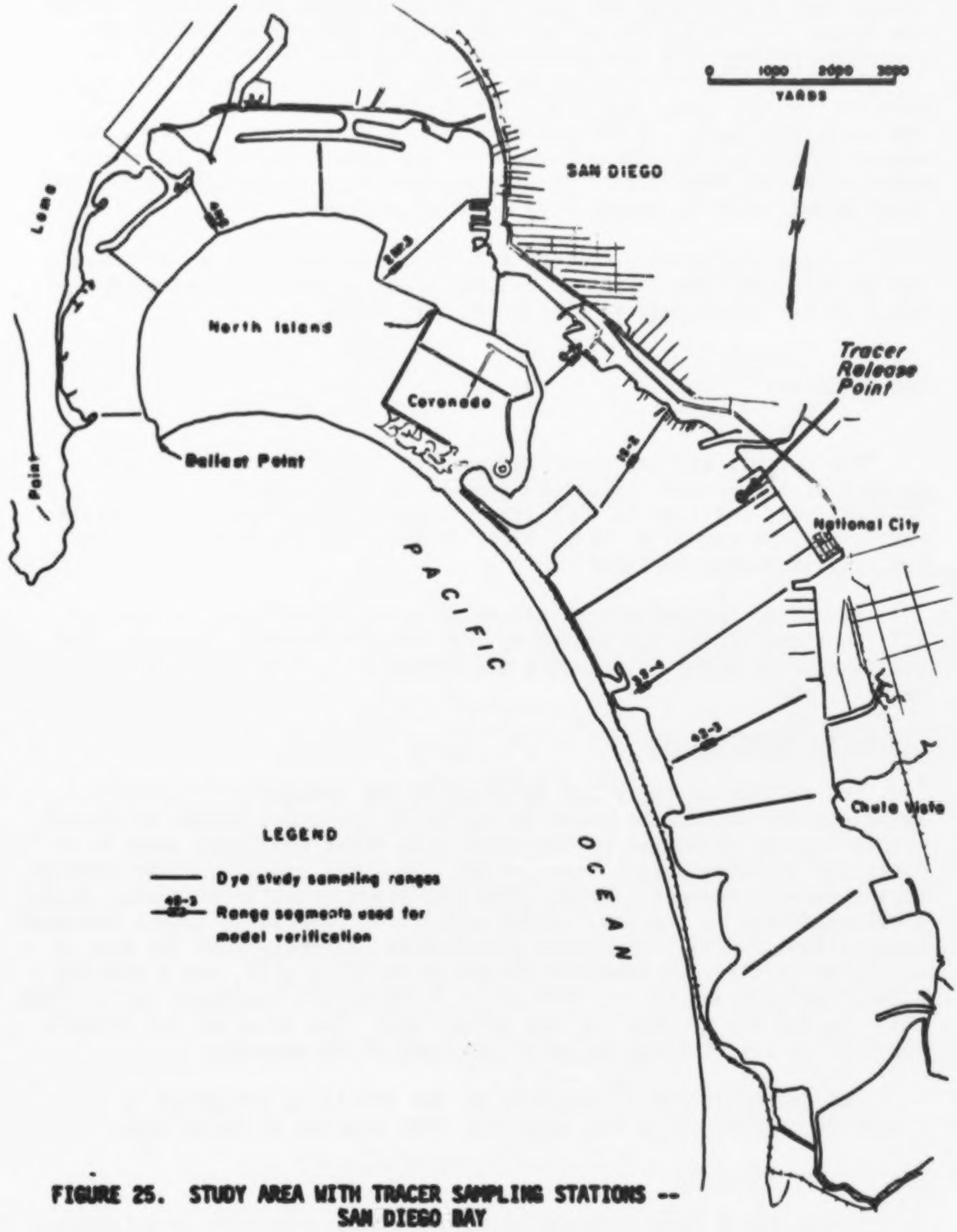


FIGURE 25. STUDY AREA WITH TRACER SAMPLING STATIONS -- SAN DIEGO BAY

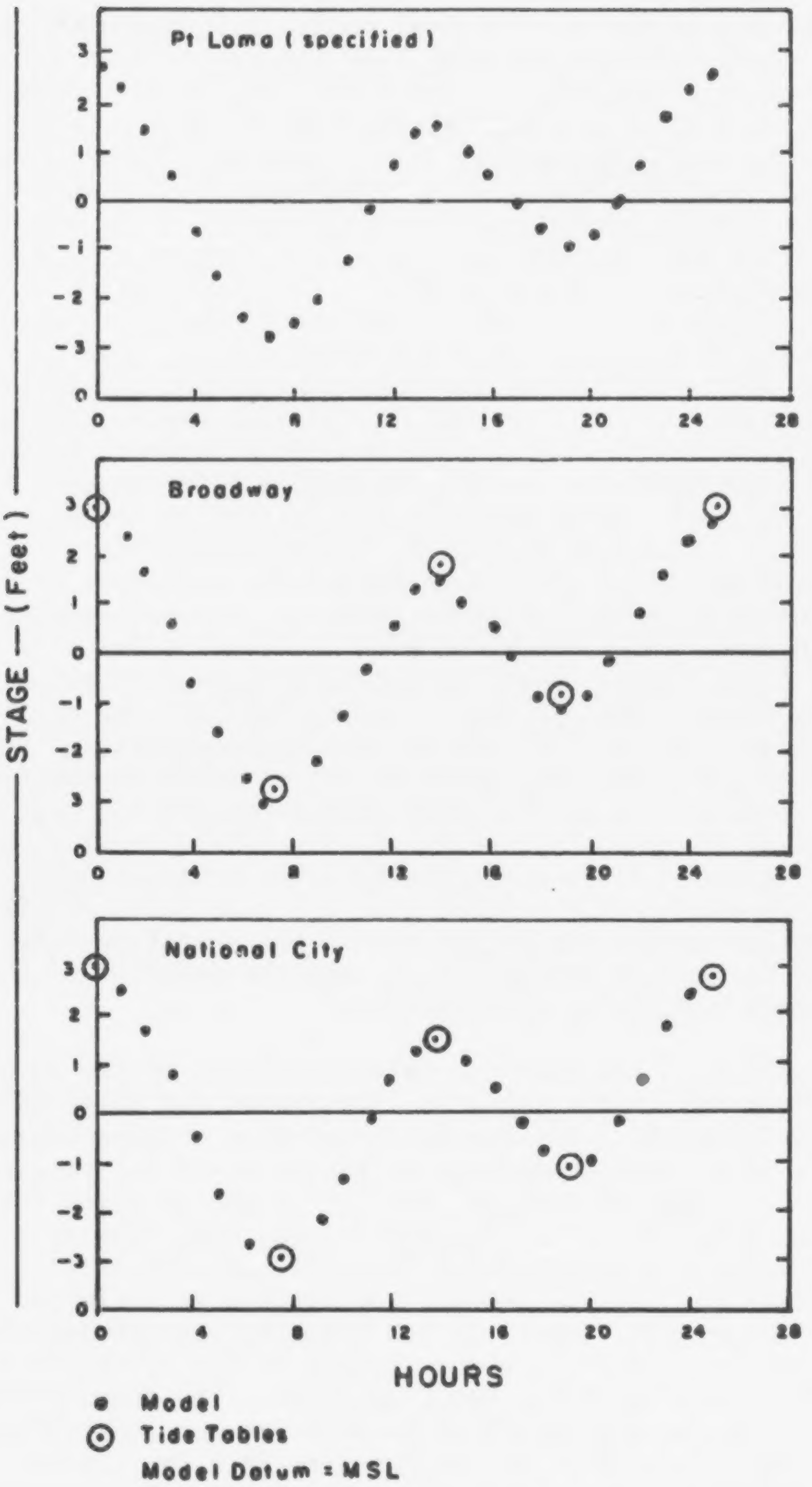


FIGURE 26. COMPARISON OF MODEL AND TIDE PREDICTIONS OF TIDAL STAGE -- SAN DIEGO BAY

in verification of the mathematical model, a 15-day continuous release of Rhodamine WT Solution was made from the end of Pier 3 in the U. S. Naval Station as indicated in Figure 25. Histories of the buildup and subsequent decline of dye concentration at various points in the Bay were prepared from these data. This tracer release was then simulated with the mathematical model and a comparison made between the model predictions and the field observations (Figures 27 to 30). For this simulation the dye was treated as non-conservative with a loss rate of 3.4 percent per day, similar to that rate determined by a study of the Potomac River estuary [20]. Background concentration specified at Point Loma corresponded to field observations. The prototype data illustrated in these figures indicate significant fluctuation in concentration from one sampling time to the next beyond what would be expected from the long-term change in concentration. This is due in part to the continuously changing hydraulic conditions in the Bay resulting from wind induced currents and changes in tidal conditions. In areas with pronounced gradients, the concentration at any point is strongly influenced by tidal excursions, and variation in excursion yields erratic station histories. However, the mathematical model used a recurring mean tidal condition with identical tidal excursion distances for every tidal cycle. Thus, no attempt was made to simulate these day to day fluctuations of the prototype but only the mean change in concentration. In addition the prototype concentrations are representative of only a relatively small volume of water at the sampling point. The model predictions on the other hand represent the mean concentration of the volume of water represented by a network junction, which might typically have a surface area one-half mile square. Other factors perhaps introducing difficulties into the simulation are the uncertainty of the loss or decay rate of the dye in the prototype, the level (and origin) of background concentration, and the question of whether the Bay is indeed vertically unstratified.

The effect of the dye loss rate specified for the simulation of the San Diego Bay tracer study is illustrated for selected stations in Figures 31 and 32. The dye was treated as a conservative constituent (zero loss rate) and was decayed at the rates of 1.7 percent per day and 3.4 percent per day, as indicated. It can be noted that the model predictions utilizing a 1.7 percent per day loss rate follow the prototype observations more closely than did the comparable rate for the San Francisco Bay study. Because there are a very limited number of significant hydraulic inputs to San Diego Bay as compared to San Francisco Bay there is much less uncertainty in the hydraulic conditions specified for the San Diego Bay simulation. The comparisons of the two dye loss rates may therefore be somewhat more meaningful for the San Diego Bay study than for the San Francisco Bay system. Wherein the 3.4 percent rate resulted in the most favorable comparison for the San Francisco Bay study the comparison for San Diego Bay does not indicate conclusively which rate gives the better comparison.

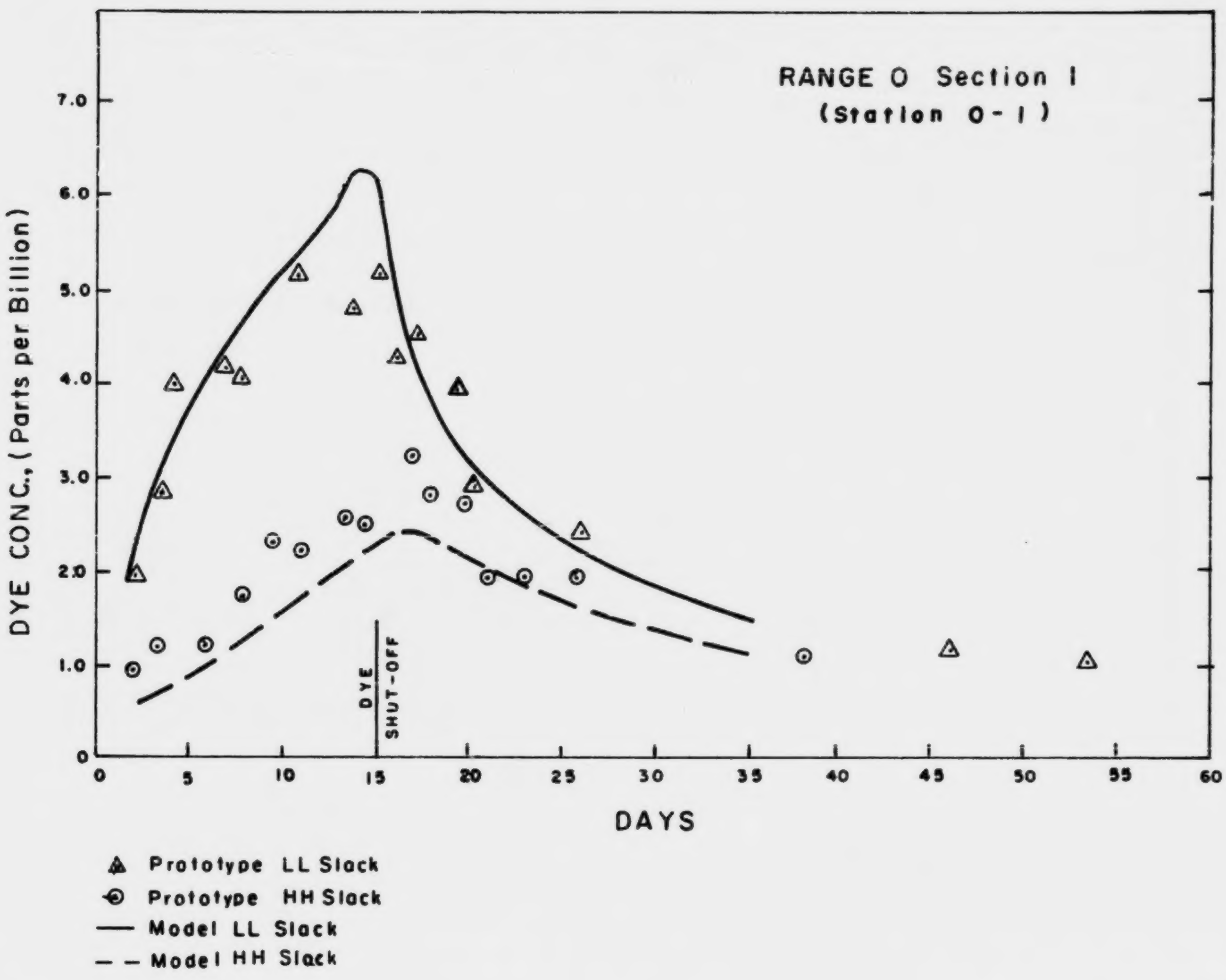


FIGURE 27. TRACER CONCENTRATION HISTORIES -- SAN DIEGO BAY

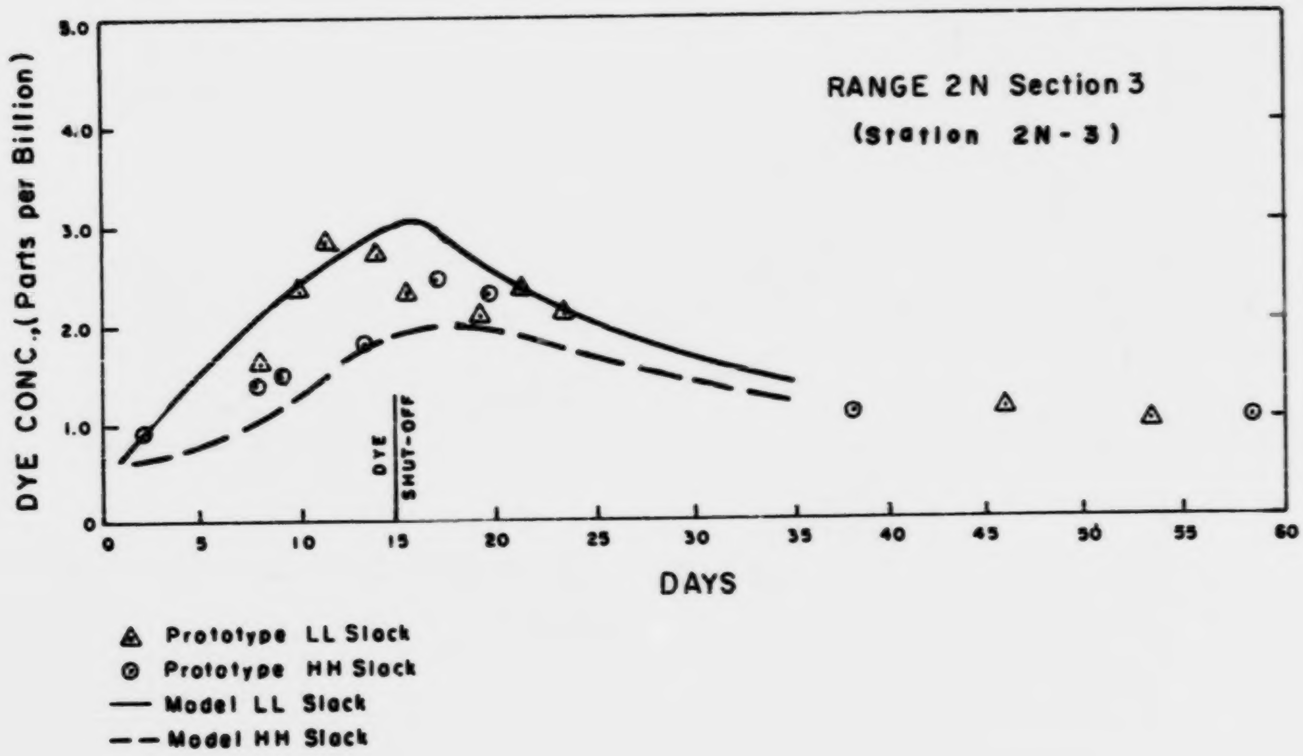


FIGURE 28. TRACER CONCENTRATION HISTORIES -- SAN DIEGO BAY

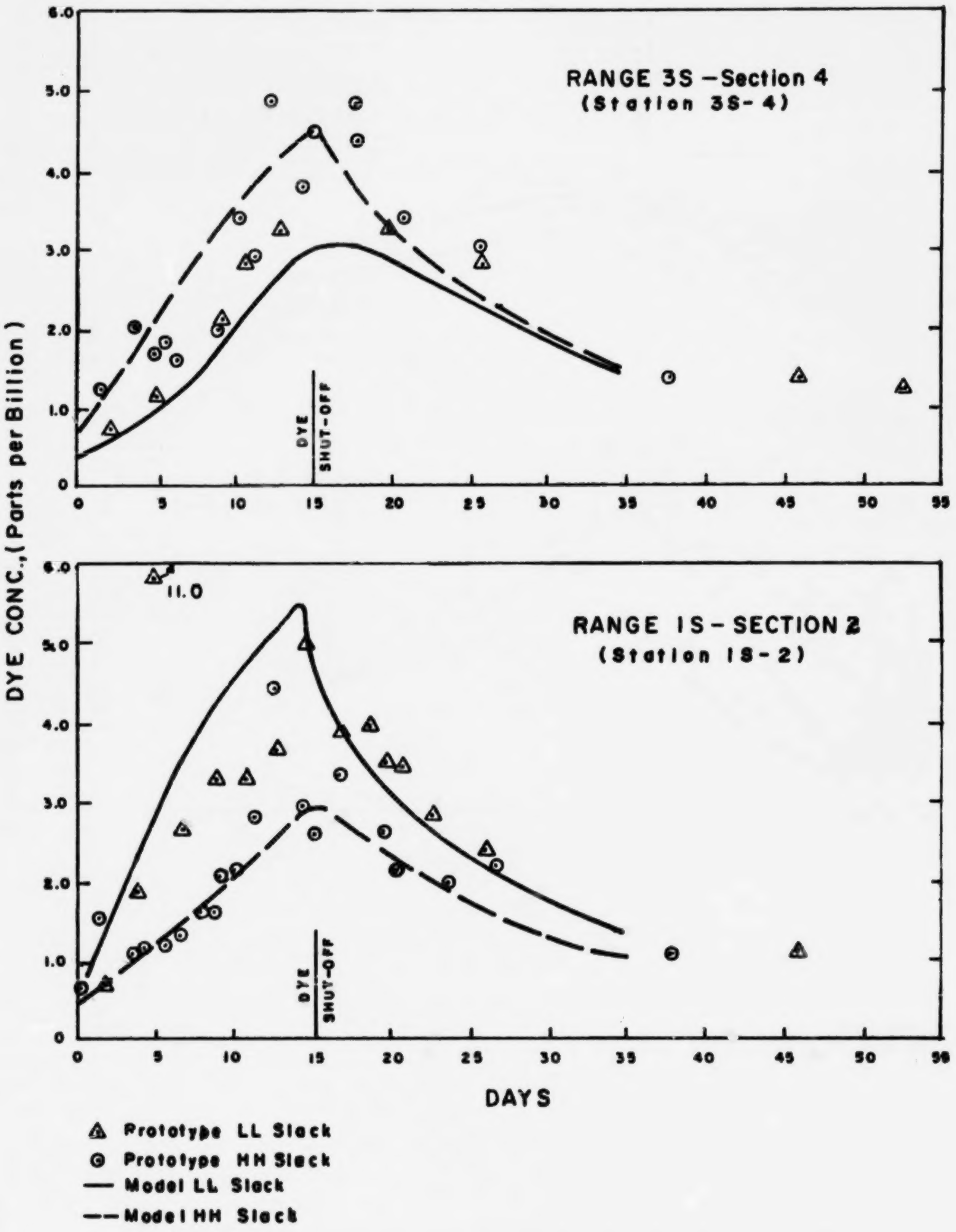


FIGURE 29. TRACER CONCENTRATION HISTORIES -- SAN DIEGO BAY

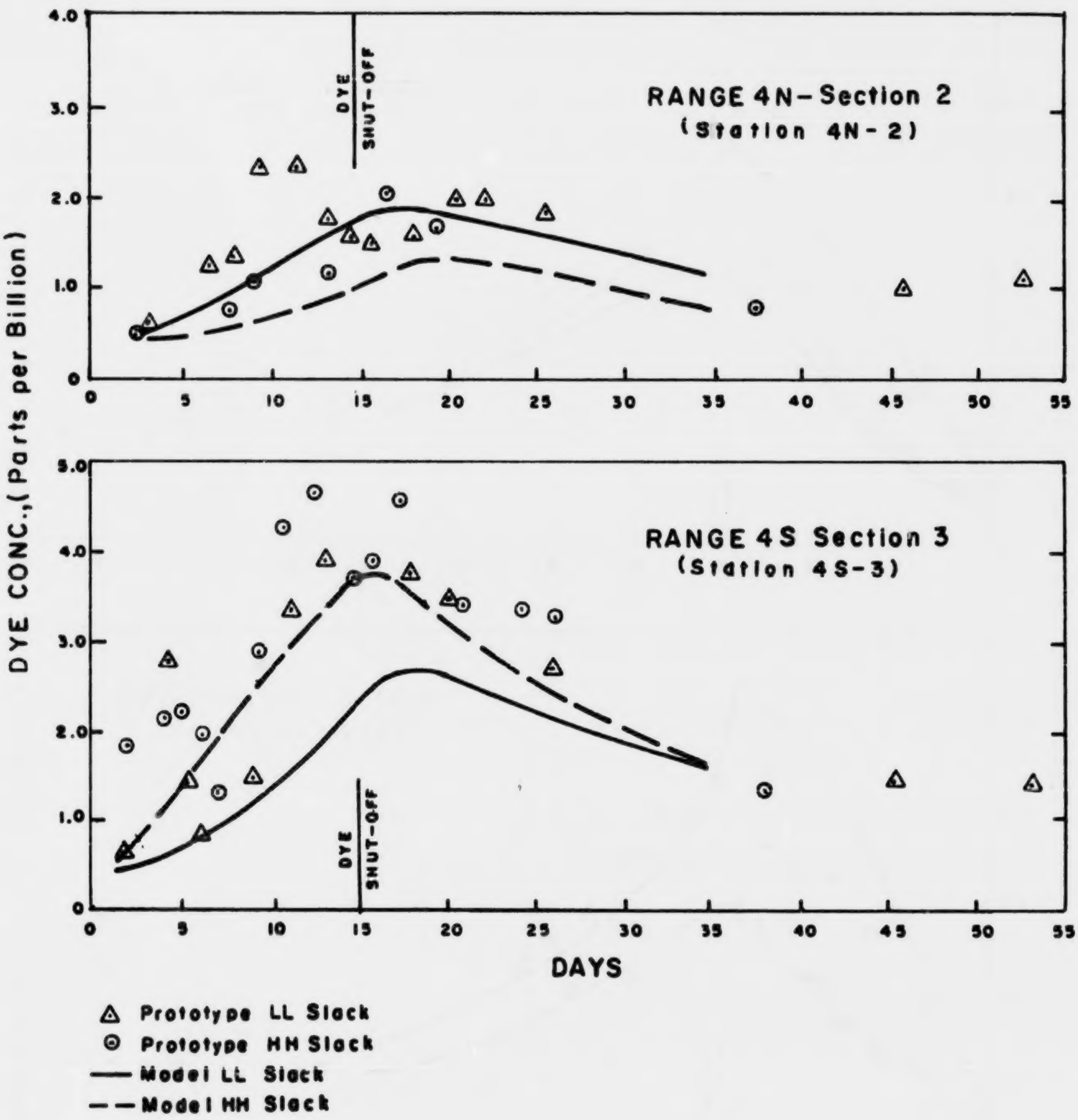


FIGURE 30. TRACER CONCENTRATION HISTORIES -- SAN DIEGO BAY

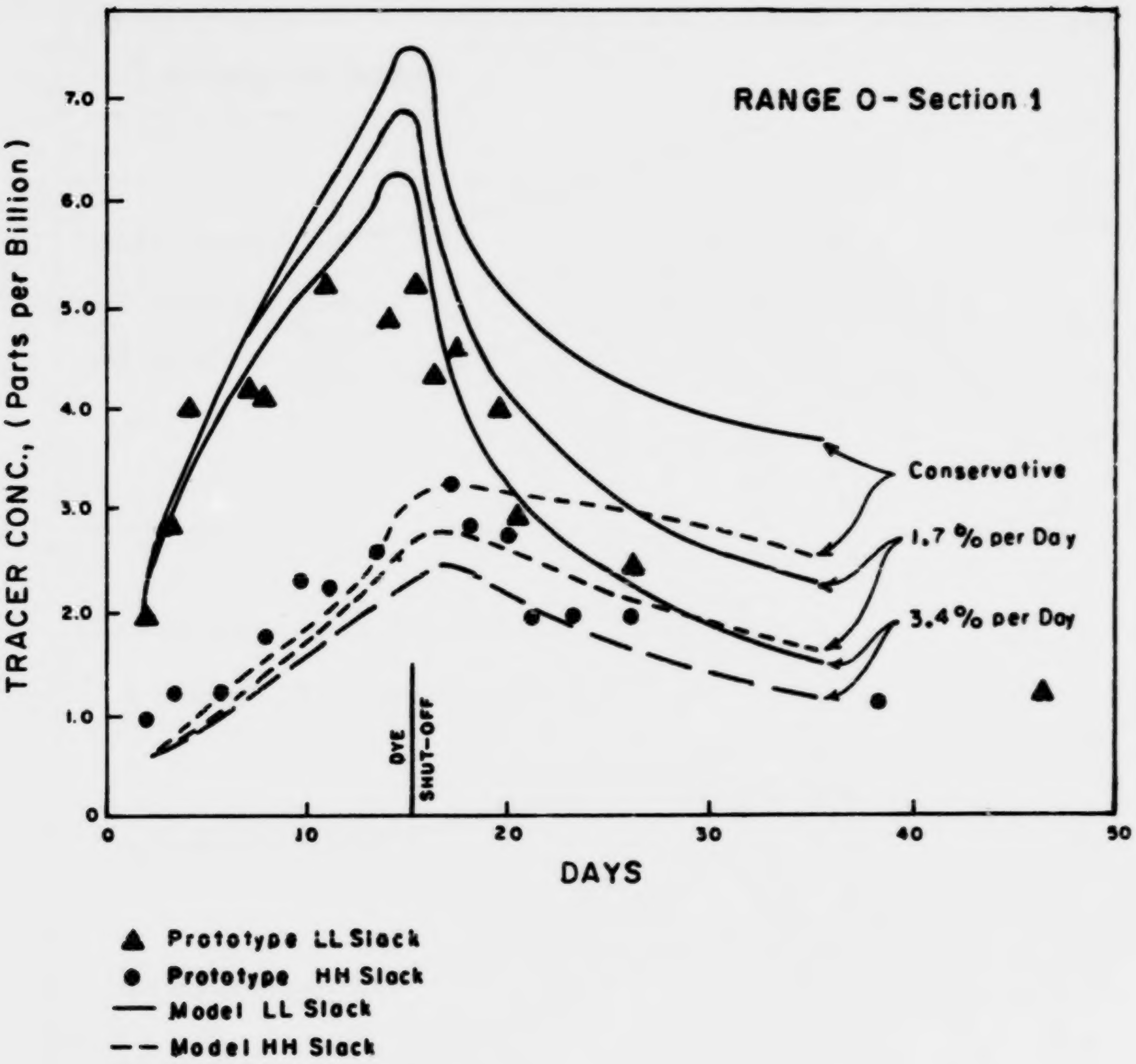


FIGURE 31. EFFECT OF SPECIFIED TRACER LOSS RATE ON MODEL PREDICTIONS -- SAN DIEGO BAY

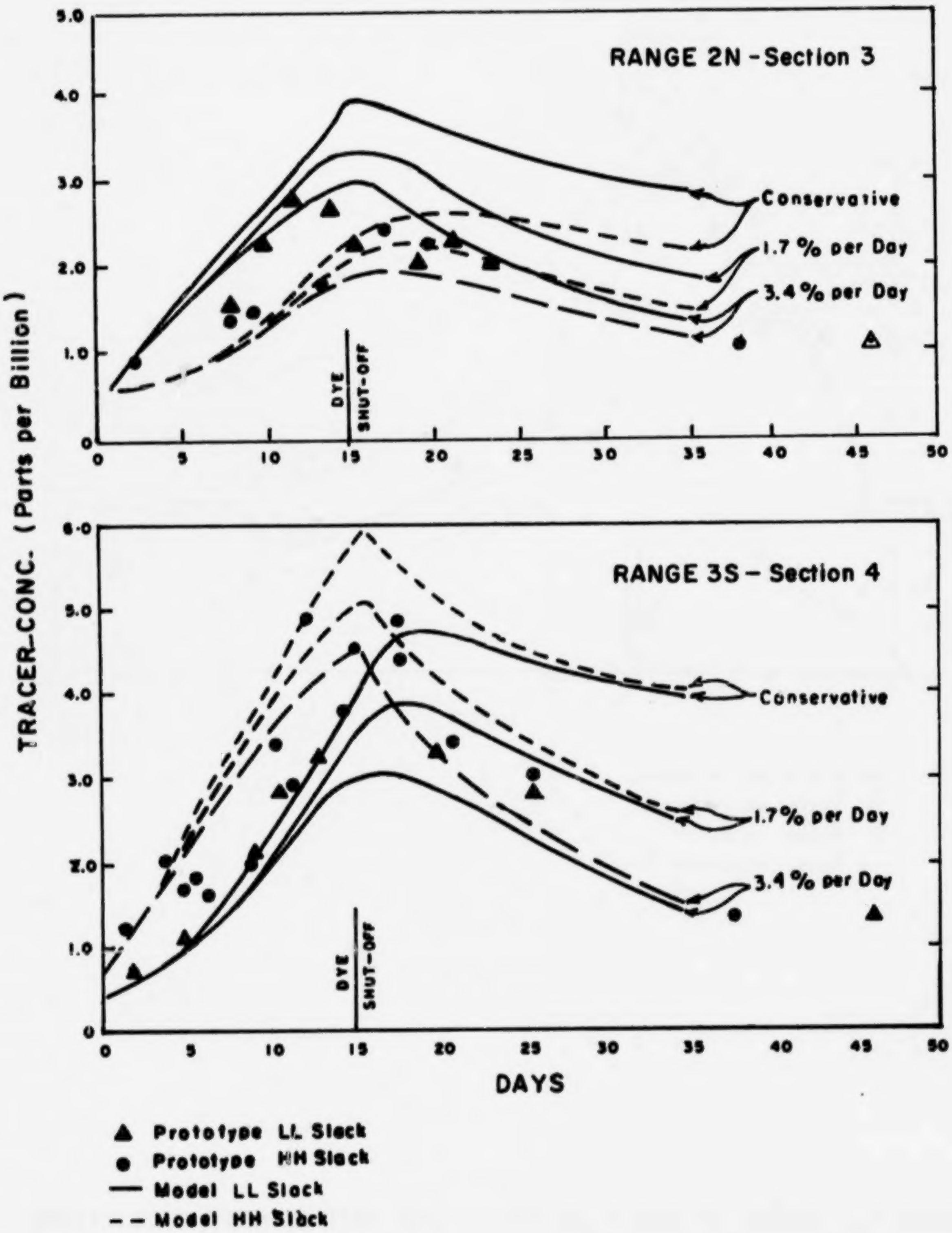


FIGURE 32. EFFECT OF SPECIFIED TRACER LOSS RATE ON MODEL PREDICTIONS -- SAN DIEGO BAY

The results of both hydraulic and quality simulations lead to the conclusion that the model is adequate to represent dispersion phenomena in San Diego Bay and permit comparison of various water quality management plans.

## LINEAR ESTUARY AND SENSITIVITY STUDIES

In addition to the verification runs discussed previously, several studies were conducted on the San Francisco and San Diego Bay systems and on an idealized linear estuary to determine the sensitivity of the hydraulic model to parameters such as time interval, network scale, and Manning "n" values and of the quality model to such parameters as time interval, network scale, diffusion coefficient, and the solution technique for advective transport.

### Hydraulic Model

Time Interval and Network Scale. The time interval used in the hydraulic solution and the lengths assigned to channel elements of the network must satisfy the stability criterion discussed in Part I. While the time and space scales can be selected with a certain degree of flexibility the range of choice may be limited by the geometry of the prototype and/or the degree of detail desired. To minimize computation time the time interval should be as large as possible; however, the stability criterion dictates a sacrifice in network detail (i.e., increasing element lengths) as the time interval is increased. Studies on an idealized linear estuary indicate that, for a given network, time intervals below the allowable maximum have little affect on the predicted hydraulic behavior of the system. Similarly, for a given time interval, increasing the lengths of the channel elements (modeling the idealized estuary with fewer elements) has little effect on the predicted channel velocities and junction heads. It must be kept in mind, however, that this analysis was conducted on an idealized system with no branching channels such as occur in real systems. In real systems there is obviously a restriction on the maximum channel lengths since they may be dictated by the geometry of the system.

Manning "n" Values. The network configuration characterizing the San Francisco Bay system was originally developed as three separate networks, one for the Delta area, another for Suisun Bay, and a third for San Pablo Bay. Each was tested independently before the three were linked into a single network. The initial hydraulic verification run on the combined network indicated several discrepancies between model predictions and prototype behavior, particularly in the area of the confluence of the Sacramento and San Joaquin Rivers in the western Delta. The predicted tidal range at stations in this area significantly exceeded the tidal range experienced in the prototype. It was not possible to determine the exact cause of the discrepancies but additional studies indicated the hydraulic solution to be rather insensitive to changes in the model network layout but quite sensitive to changes in channel roughness coefficients.

The model structure does not account for energy losses due to changes in momentum at junctions. At major junctions, such as at the confluence of the Sacramento and San Joaquin Rivers, where the streams meet at essentially a right angle, it is possible to compensate for the momentum energy loss through increased friction losses. For the case in question the roughness coefficients in the channels entering such junctions were increased with significant results as illustrated in Figure 33. Typically the values of the Manning coefficients were increased from values around 0.025 up to values of 0.050 at the extreme.

### Quality Model

The effects of varying the quality time step, the network scale, the dispersion coefficient, and the method of advective transport can be evaluated separately; however the effects may or may not be independent and the net combined effect may be difficult to predict from independent sensitivity analyses on the various parameters. While it is possible that a single criterion which would define the optimum combination of time interval, network scale, diffusion coefficient, and method of advective transport exists for the quality program, no such relationship has yet been developed. Because the criterion would also have to be compatible with the hydraulic stability criterion discussed previously, the definition of such a relationship is not likely to be simple.

Time Interval and Network Scale. Because the quality program utilizes the identical network used in the hydraulic solution it is not possible to independently alter the network scale. A new hydraulic solution must be obtained for each different network layout desired. In studies utilizing the idealized linear estuary wherein the number of network nodes and channels to model the system was decreased approximately two-thirds, the quality predictions for simulated salinity incursion were not significantly affected although a slight increase in incursion was noted.

Studies to evaluate the effect of the quality time step have been conducted on the San Francisco and San Diego Bay systems and on the linear estuary. Figure 34 illustrates the effect on the concentration profile at both high and low tide, of varying the time step for the linear estuary. This study indicates increasing upstream dispersion with decreasing time steps.

The predicted rate of transport from a point source was evaluated for the San Francisco Bay system utilizing time steps of one-quarter and one-half hour. Comparison of model predictions with prototype observations is presented in Figures 35 and 36. During the initial period of the release the maximum concentration at a station results from utilizing the smaller time step. The constituent is moved the same distance (from one junction to another) regardless of the time step;

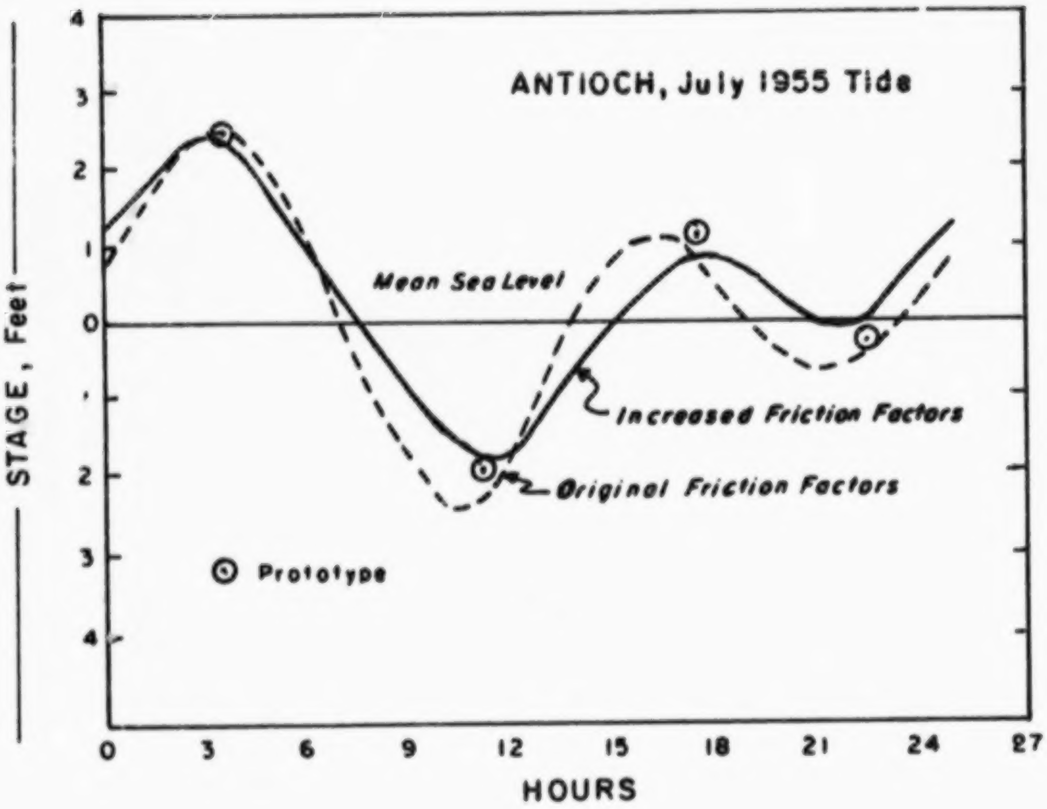


FIGURE 33. EFFECT OF INCREASED CHANNEL RESISTANCE ON COMPUTED TIDAL STAGE AND PHASE

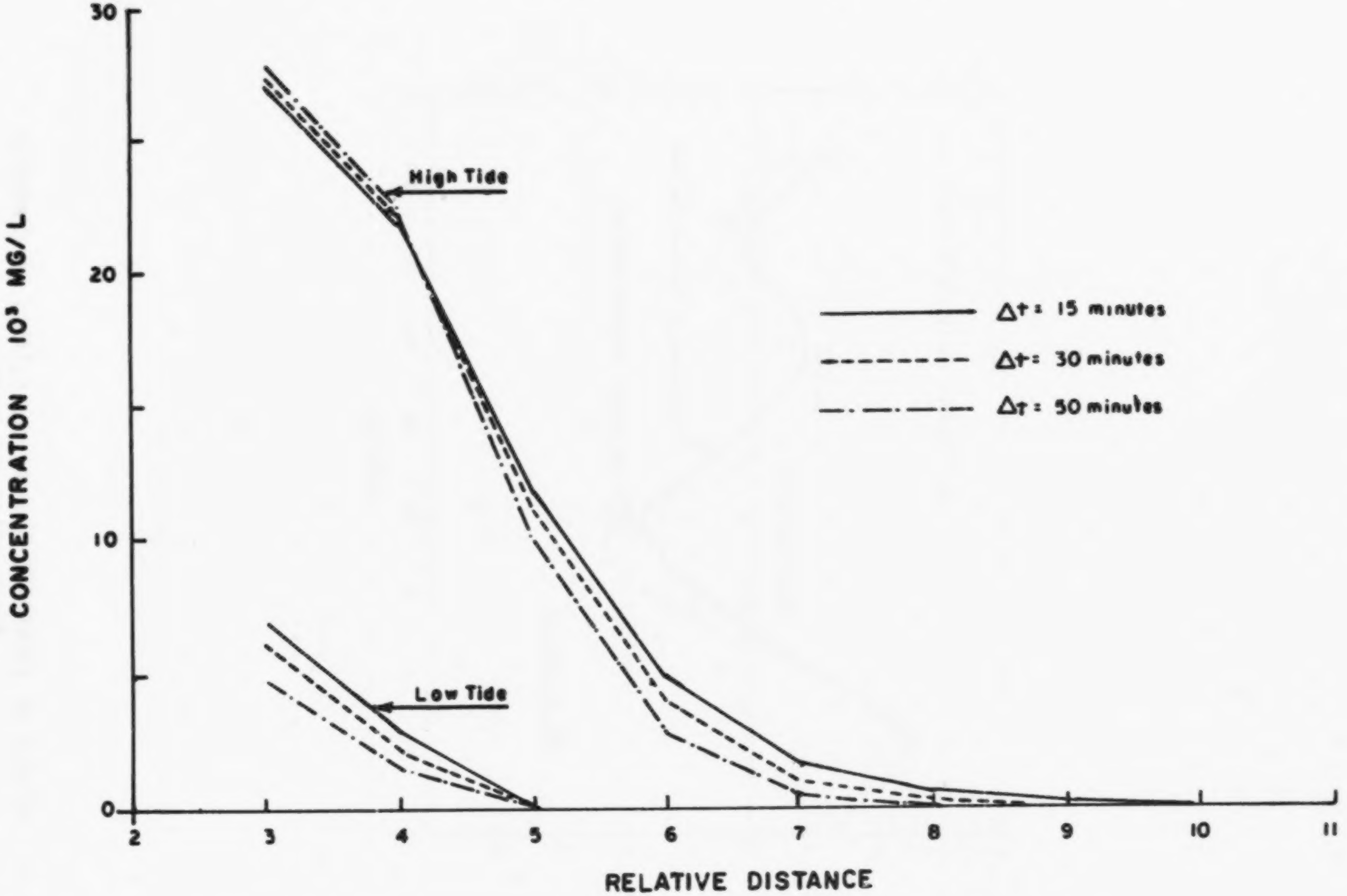


FIGURE 34. EFFECT OF TIME INTERVAL ON INTRUSION IN A SIMPLE LINEAR CHANNEL

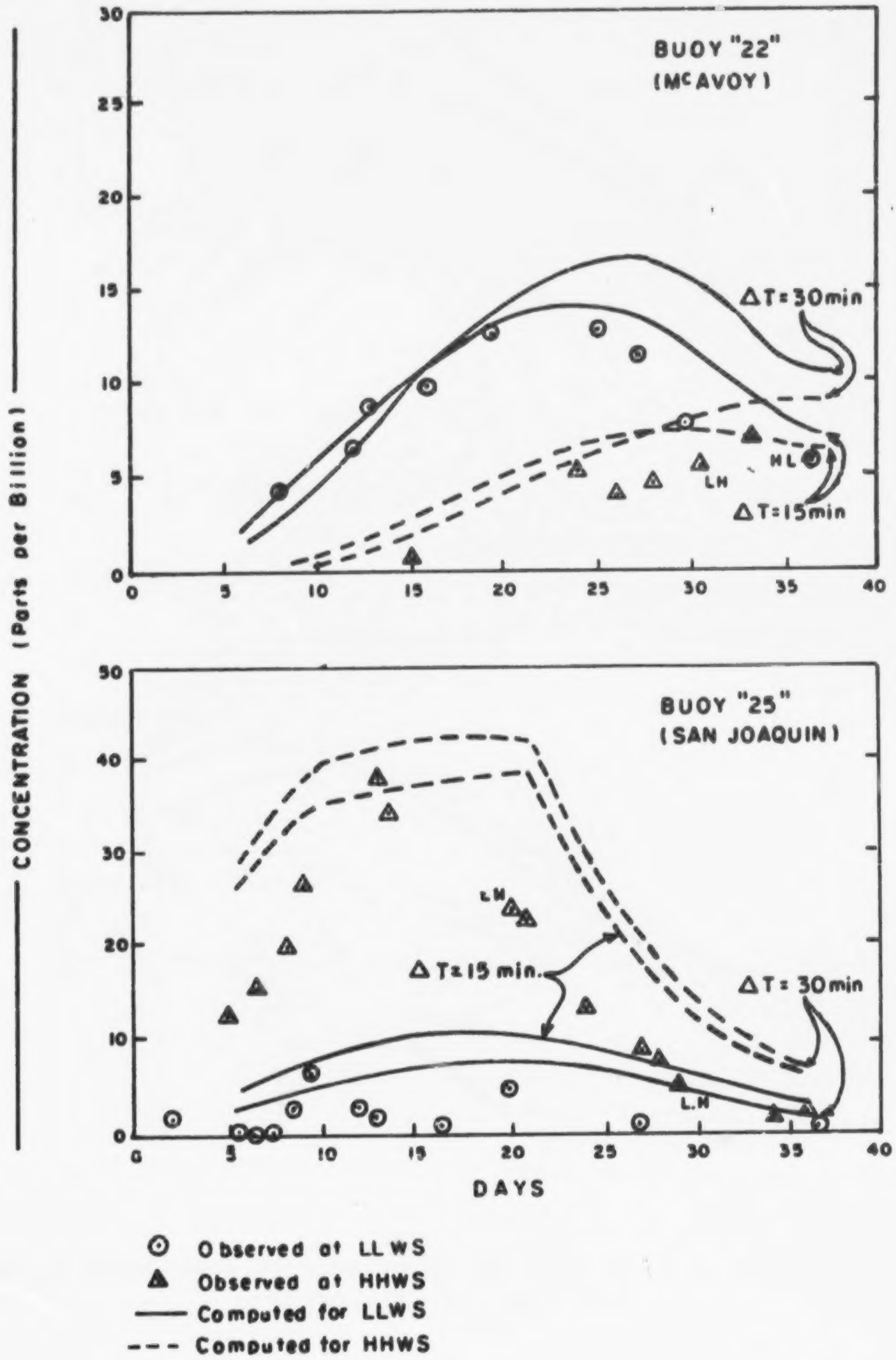


FIGURE 35. EFFECT OF TIME INTERVAL ON DISPERSION FROM POINT SOURCE -- SAN FRANCISCO BAY-DELTA

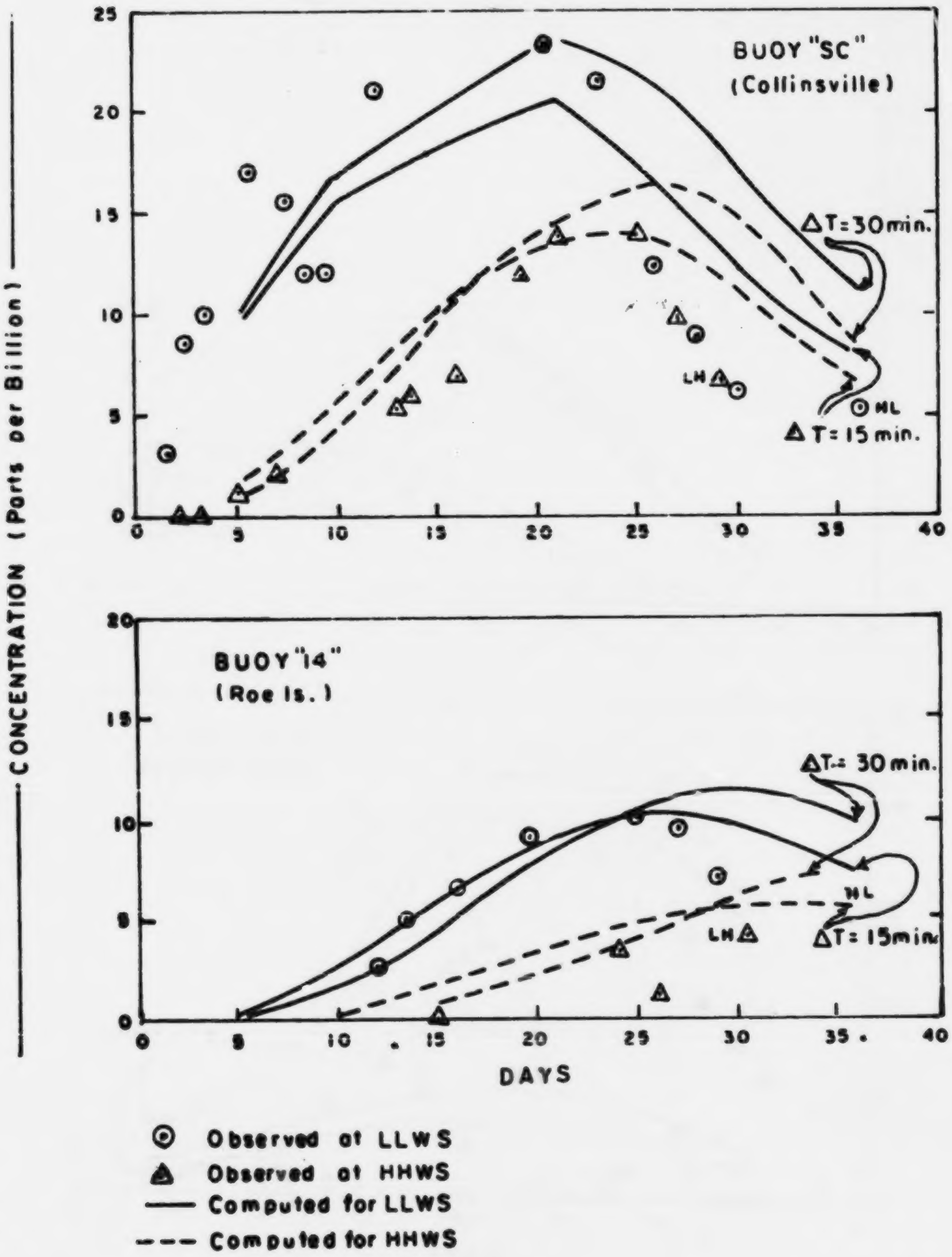


FIGURE 36. EFFECT OF TIME INTERVAL ON DISPERSION FROM POINT SOURCE -- SAN FRANCISCO BAY-DELTA

therefore the tracer "front" will progress most rapidly from the release point utilizing the smaller time step. On the other hand the total mass of constituent transferred between two junctions during each time step is greater for the larger time interval, which can result in a more rapid buildup at a station. This is reflected in Figures 35 and 36 wherein the curves for the one-half hour interval start out below those for the quarter hour interval for most stations but rise more rapidly and eventually cross the quarter-hour curves. There are of course, other complicating factors which affect the shape of the curves, including the transfer of constituent by diffusion and the method utilized to specify the concentration in the advective transport term. These factors will be discussed subsequently.

The predicted rate of dispersion from a point source was evaluated on the San Diego Bay system utilizing time steps of one-eighth, one-quarter, and one-half hours as illustrated in Figures 37 and 38. For this comparison, the tracer was treated as conservative: hence no comparison with prototype observations is included. As for the San Francisco Bay system the maximum concentrations were obtained utilizing a one-half hour time step even though the concentrations for that time step started out below those for the two smaller steps at most stations. Because of other complicating factors it is again not possible to separate out the effect due solely to the time step.

Diffusion Coefficient. As discussed previously the quality model predictions are rather insensitive to the magnitude of the diffusion coefficient used in the solution. This is illustrated in Tables 3 and 4 which show the effect of increasing the constant used for calculating the diffusion coefficient ($C_4$ in eq. 26, p. 22) by a factor of 100 (0.025 to 2.5) for, respectively, the San Francisco Bay and San Diego Bay systems. As can be noted most of the differences are less than ten percent in both systems, with larger differences mostly associated with low concentrations where a small change in concentration represents a significant percent change. Roundoff error also can influence such small numbers significantly.

At first glance there is no apparent consistency in the changes noted in the Tables. However if the location of each station is considered it can be noted that the higher constant yields higher maximum concentrations at stations far removed from the release point and in lower maximum concentrations at stations near the release point. Such a phenomenon is expected since the higher diffusion coefficient should result in more rapid transport of a constituent away from the release point resulting in a lower concentration peak but with higher surrounding concentrations. The lower diffusion constant should yield a higher peak concentration at or near the release point but with a rapid dropoff with distance from the peak.

Solution Technique for Advective Transport. Equation 38 presented previously defines the mass transfer in a general channel element. This can also be expressed as:

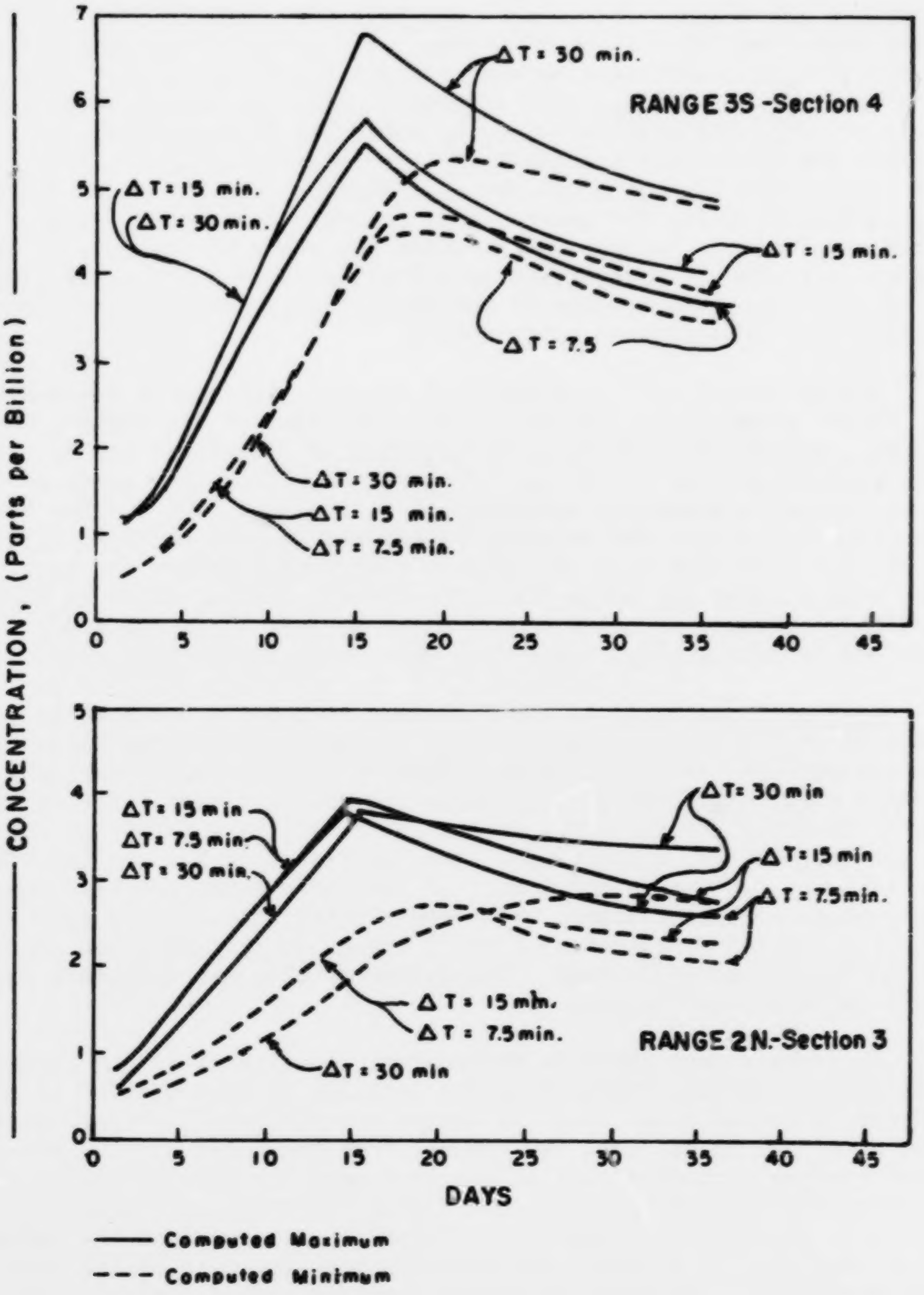


FIGURE 37. EFFECT OF TIME INTERVAL ON DISPERSION OF CONSERVATIVE TRACER FROM POINT SOURCE -- SAN DIEGO BAY

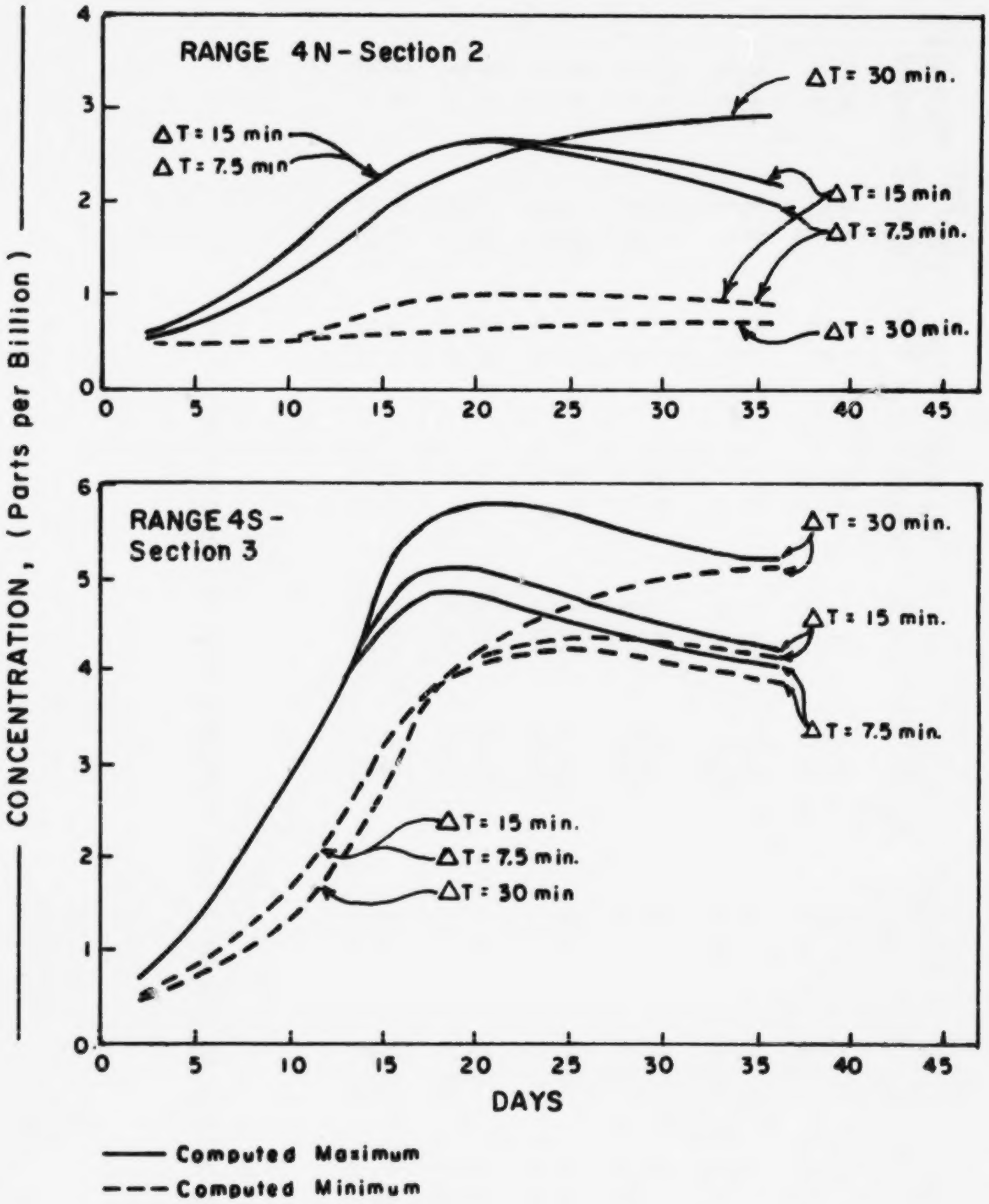


FIGURE 38. EFFECT OF TIME INTERVAL ON DISPERSION OF CONSERVATIVE TRACER FROM POINT SOURCE -- SAN DIEGO BAY

TABLE 3. EFFECT OF DIFFUSION CONSTANT, $C_4$, ON MODEL PREDICTIONS--SAN FRANCISCO BAY

| Station | | 10 Days | | | 16 Days | | | 21 Days | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conc., ppb* | | Percent Change | Conc., ppb* | | Percent Change | Conc., ppb* | | Percent Change |
| | | $C_4$= 0.025 | $C_4$= 2.5 | | $C_4$= 0.025 | $C_4$= 2.5 | | $C_4$= 0.025 | $C_4$=2.5 | |
| Buoy "14" | Min. | .1 | .1 | 0 | 1.0 | 1.1 | +10 | 2.5 | 2.9 | +16 |
| (Roe Is.) | Max. | 1.2 | 1.3 | + 8 | 4.5 | 5.3 | +18 | 7.8 | 8.7 | +12 |
| Buoy "22" | Min. | .2 | .2 | 0 | 1.7 | 2.1 | +24 | 3.8 | 4.4 | +16 |
| (McAvoy) | Max. | 3.9 | 4.1 | + 5 | 10.1 | 10.8 | + 7 | 14.1 | 14.5 | + 3 |
| Buoy "25" | Min. | .9 | 1.1 | +22 | 3.8 | 4.5 | +18 | 6.9 | 7.8 | +13 |
| (Chipps Is) | Max. | 7.1 | 7.3 | + 3 | 15.7 | 16.2 | + 3 | 19.7 | 19.6 | - 1 |
| Buoy "SC: | Min. | 4.3 | 4.5 | + 5 | 10.2 | 11.0 | + 8 | 14.4 | 14.7 | + 2 |
| (Collinsville) | Max. | 17.0 | 16.8 | - 1 | 20.8 | 20.9 | + 1 | 24.1 | 23.5 | - 2 |
| Light "5" | Min. | 3.8 | 4.1 | + 8 | 10.0 | 10.6 | + 6 | 13.8 | 14.5 | + 5 |
| (New York Sl.) | Max. | 40.5 | 39.3 | - 3 | 53.5 | 50.6 | - 5 | 56.3 | 52.5 | - 7 |
| Buoy "25" | Min. | 5.3 | 5.7 | + 7 | 6.5 | 7.3 | +12 | 6.8 | 7.4 | + 9 |
| (San Joaquin R.) | Max. | 39.8 | 39.3 | - 1 | 43.9 | 42.3 | - 4 | 44.5 | 42.1 | - 5 |

*All concentrations predicted utilizing one-half hour time step and 3.4 percent per day dye loss rate.

TABLE 4. EFFECT OF DIFFUSION CONSTANT, $C_4$, ON MODEL PREDICTIONS--SAN DIEGO BAY

| | | 6 1/2 Days | | | 14 1/2 Days | | | 22 Days | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conc., ppb* | | Percent Change | Conc., ppb* | | Percent Change | Conc., ppb* | | Percent Change |
| | | $C_4$= 0.025 | $C_4$= 2.5 | | $C_4$= 0.025 | $C_4$= 2.5 | | $C_4$= 0.025 | $C_4$= 2.5 | |
| Range 4N | Min. | .5 | .5 | 0 | .5 | .5 | 0 | .5 | .6 | +20 |
| Section 2 | Max. | .7 | .8 | +14 | 1.6 | 1.8 | +13 | 2.4 | 2.6 | + 8 |
| Range 2N | Min. | .7 | .8 | +14 | 1.7 | 1.9 | +12 | 2.5 | 2.6 | + 4 |
| Section 3 | Max. | 1.6 | 1.7 | + 6 | 3.4 | 3.6 | + 6 | 3.6 | 3.6 | 0 |
| Range 0 | Min. | .9 | 1.0 | +11 | 2.2 | 2.4 | + 9 | 3.0 | 3.1 | + 3 |
| Section 1 | Max. | 7.0 | 6.1 | -13 | 10.9 | 9.7 | -11 | 6.3 | 5.7 | - 9 |
| Range 1S | Min. | 1.3 | 1.4 | + 8 | 3.1 | 3.3 | + 6 | 3.7 | 3.6 | - 3 |
| Section 2 | Max. | 6.7 | 6.0 | -10 | 10.5 | 9.5 | -10 | 6.3 | 5.7 | -10 |
| Range 3S | Min. | 1.4 | 1.3 | - 7 | 4.2 | 4.1 | - 2 | 5.7 | 5.3 | - 7 |
| Section 4 | Max. | 3.0 | 2.8 | - 7 | 6.9 | 6.4 | - 7 | 6.5 | 5.9 | - 9 |
| Range 4S | Min. | .8 | .8 | 0 | 2.6 | 2.6 | 0 | 4.5 | 4.4 | - 2 |
| Section 3 | Max. | 1.7 | 1.7 | 0 | 5.0 | 4.8 | - 4 | 6.0 | 5.6 | - 7 |

*All concentrations predicted utilizing one-half hour time step and zero loss rate

$$M_a = Q\, c^* \,\Delta t \qquad (45)$$

where

$M_a$ = advected mass

$Q$ = flow in channel

$c^*$ = representative concentration

$\Delta t$ = time step

This equation can be applied to a typical channel element, as shown in Figure 39, which connects two junctions "a" and "b". A junction volume is defined by the volumes of the half-channels entering the junction and the concentration existing at the junction exists uniformly throughout the volume (as per the assumption of complete mixing at junctions). For computational purposes, however, it is convenient to consider the concentrations at junctions as point concentrations connected by linear gradients as indicated in Figure 39. During a given time step $\Delta t$ the actual fluid displacement along a channel is equivalent to $U\Delta t$ which is frequently much shorter than the actual channel length $X$. The transfer of a quality constituent, however, is from one junction to another (the full channel length) regardless of the magnitude of the fluid displacement. A certain mass of constituent is therefore advanced ahead of the fluid. This "numerical mixing" can lead to inaccuracies in the solution, especially in regions of steep concentration gradients. The ratio of the fluid displacement $U\Delta t$ to the channel length $X$ is a crude measure of the degree to which this "induced disperson" may affect the solution. Obviously, when the ratio $\phi$ as defined in equation 46,

$$\phi = \frac{U\Delta t}{X} \qquad (46)$$

is at, or near, unity the numerical mixing problem is minimized. In a given channel in a dynamic tidal system $\phi$ will approach zero near the occurrence of slack water and normally only approaches unity during periods of maximum tidal velocity. Numerical mixing can therefore be significant over much of the tidal cycle. The magnitude of the problem is largely dependent on the specification of $c^*$ in equation 45 which determines the mass of constituent transferred. The concentration $c^*$ is determined by an arbitrary function of $c_a$ and $c_b$:

$$c^* = f(c_a, c_b) \qquad (47)$$

In its simplest form $c^*$ is taken as the concentration existing at the upstream junction. Thus, if $Q$ is in the direction shown in Figure 39 then $c^* = c_a$. Experience with this approach on the San Francisco Bay system indicated excessive numerical mixing (excessive dispersion). Four other functional relationships have been investigated and evaluated as summarized in Table 5. Each technique was evaluated for degree of numerical mixing, accuracy of solution, and computational stability, as indicated.

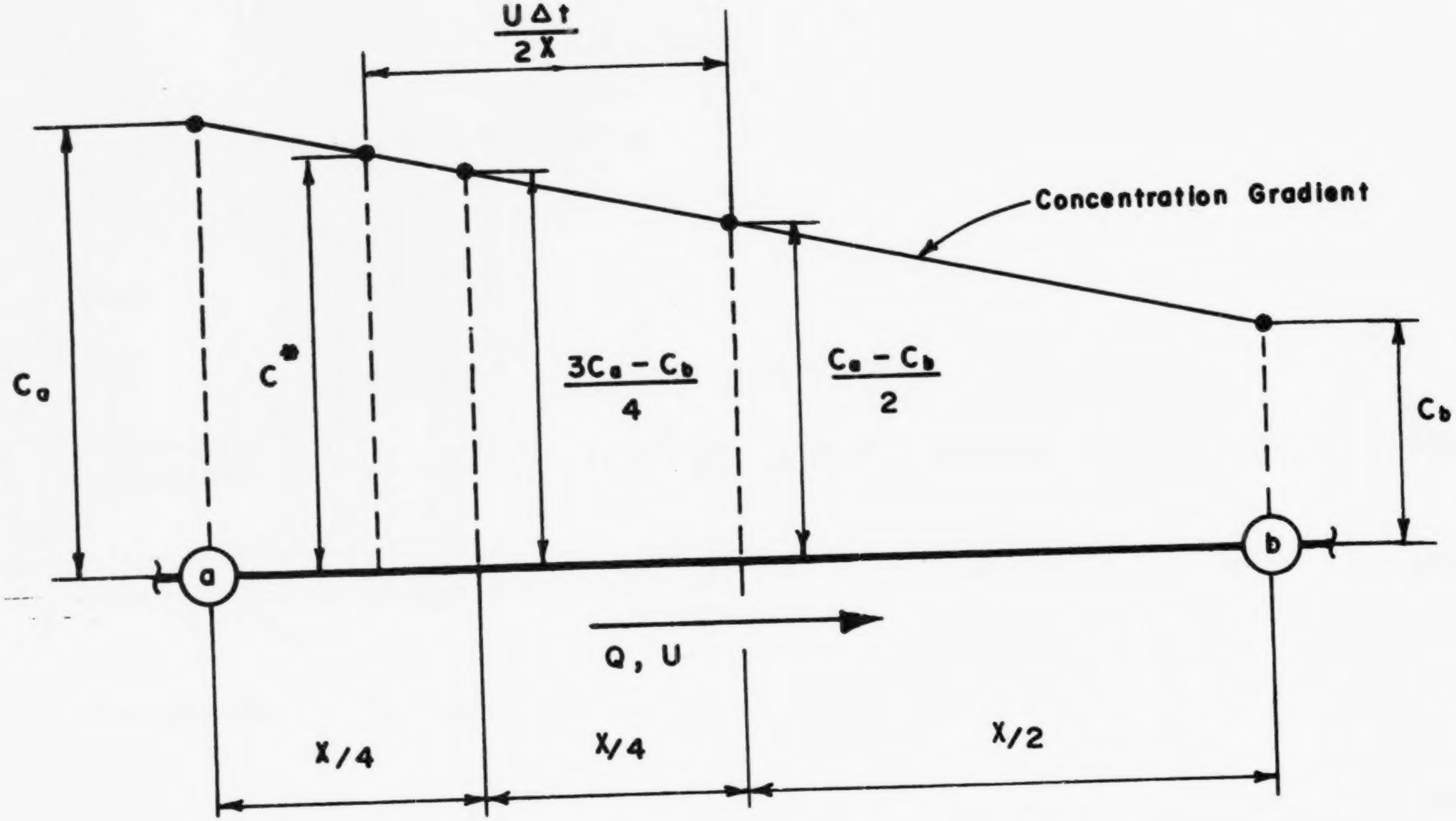


FIGURE 39. TYPICAL CHANNEL ELEMENT AND CONCENTRATION GRADIENT

## TABLE 5. COMPARISON OF ADVECTION METHODS

| Method | Definition of c* | Numerical Mixing | Accuracy | Stability |
|---|---|---|---|---|
| UPSTREAM | $c^* = c_a$ | High | Poor | Excellent |
| SIMPLE AVERAGE | $c^* = \frac{c_a + c_b}{2}$ | Low | Good | Very Poor |
| QUARTER POINT | $c^* = \frac{3c_a + c_b}{4}$ | Moderate | Good | Acceptable |
| PROPORTIONAL (TWO-WAY) | $c^* = \frac{c_a + c_b}{2} + \phi\left(\frac{c_a - c_b}{2}\right)$ | Low | Good | Poor |
| PROPORTIONAL (ONE-WAY) | $c^* = \frac{c_a + c_b}{2} + \phi\left(\frac{c_a - c_b}{2}\right)$, if $c_a > c_b$<br>$c^* = c_a$ , if $c_a < c_b$ | Moderate | Moderate | Good |

Note:

$$\phi = \frac{U\Delta t}{X}$$

$c_a, c_b$ are as indicated in Figure 39

Computational instability may occur whenever significantly more mass is removed from a junction than is added during a time step (or series of time steps) resulting in a sharp drop in the concentration at one junction and a sharp increase at an adjacent one. The instability does not normally correct itself and the concentration gradient becomes very steep resulting in a zero or negative concentration at one junction and an extremely high concentration at an adjoining junction. This instability is prevented from continuing by a trap in the program which terminates execution whenever the concentration at any junction exceeds a specified value.

Figure 40 illustrates the results of testing four of the five techniques on the San Francisco Bay system. Identical hydrologic and quality boundary conditions were specified in all cases. No comparison is included for the Simple Average method listed in Table 5 because it was so unstable that a solution could not be obtained for the problem studied. The Figure depicts the predicted salinity gradient through the main channel of the system after approximately thirty tidal cycles. The starting concentrations at all stations were identical for each method; therefore the total mass of chloride in the system is the same in each case.

The Proportional Two-way and Quarter-point methods produce the most pronounced gradients through the system (typifies the least numerical mixing). The significance of the numerical mixing problem is illustrated in Figures 41 and 42 by comparing the three most stable solution techniques with observed prototype behavior at several stations in the system. The most significant differences are noted at stations near the salinity front (Antioch, Isleton, Collinsville, and O&A Ferry) with only minor differences in the fresh water (as typified by Mossdale Bridge) and saline (as typified by Benicia) portions of the estuary.

Slight differences in the concentrations for the initial day of the month are apparent at some stations; however this is due to the solution techniques and not to differences in starting conditions. The concentrations plotted for time zero are the maximums computed during the first 24 hours of the simulation and are not the initial concentrations specified as input. The effect of starting concentrations was illustrated earlier.

The results of these and other studies indicated that the Quarter-point and Proportional Two-way methods most adequately represent prototype behavior. However, instability problems with the latter method are significant and therefore, the Quarter-point method has been used exclusively in FWQA studies.

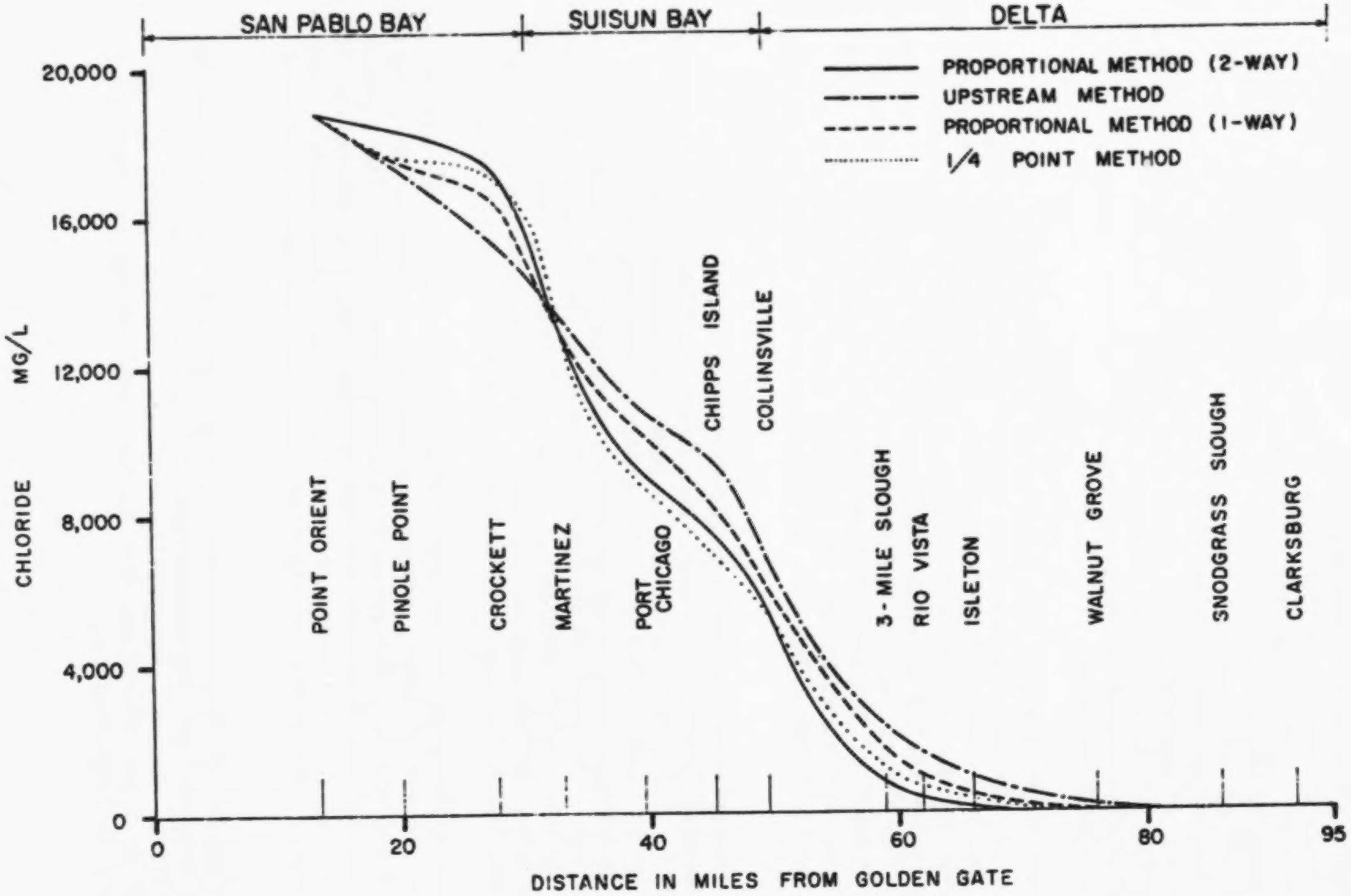


FIGURE 40. COMPARISON OF SOLUTION TECHNIQUES

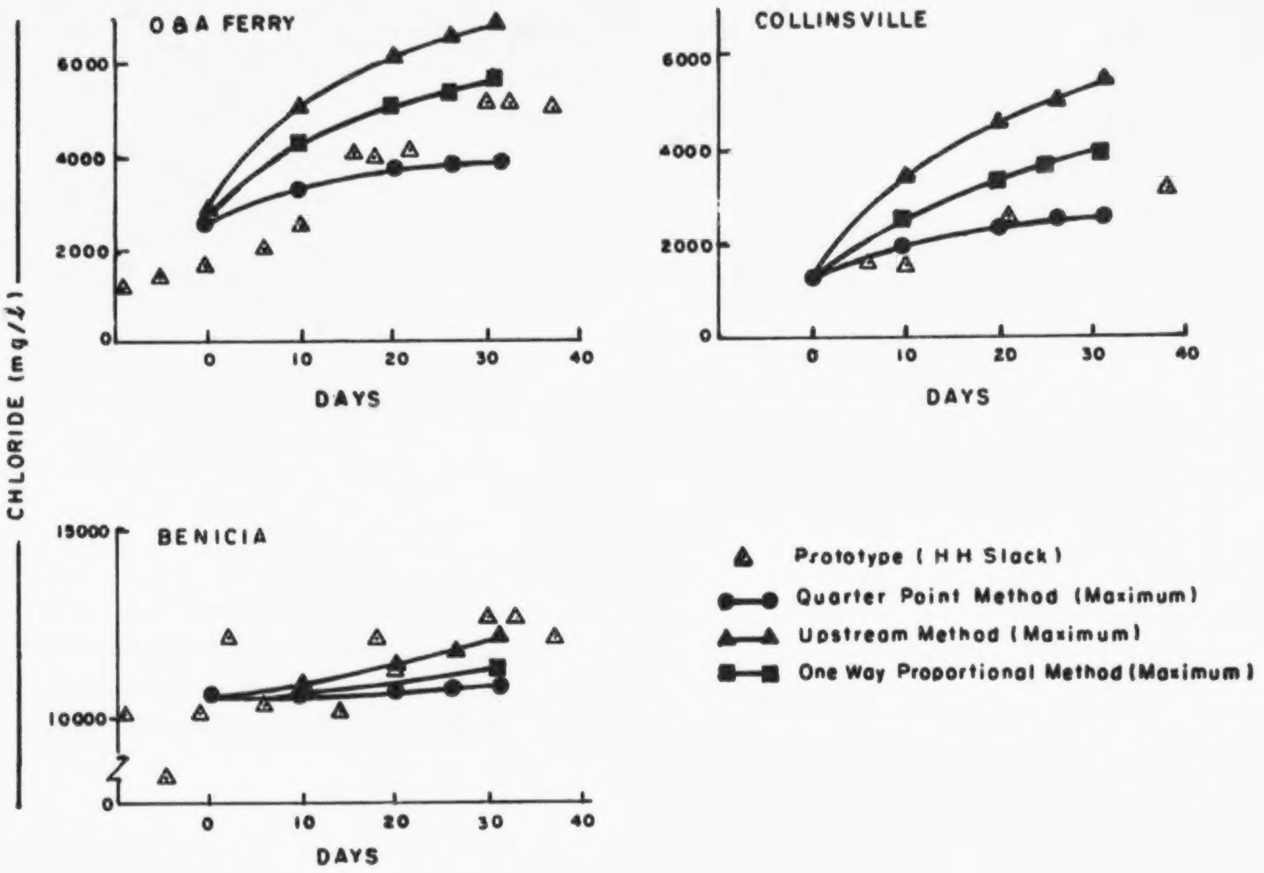


FIGURE 41. COMPARISON OF SOLUTION TECHNIQUES -- JULY 1955 CHLORIDE

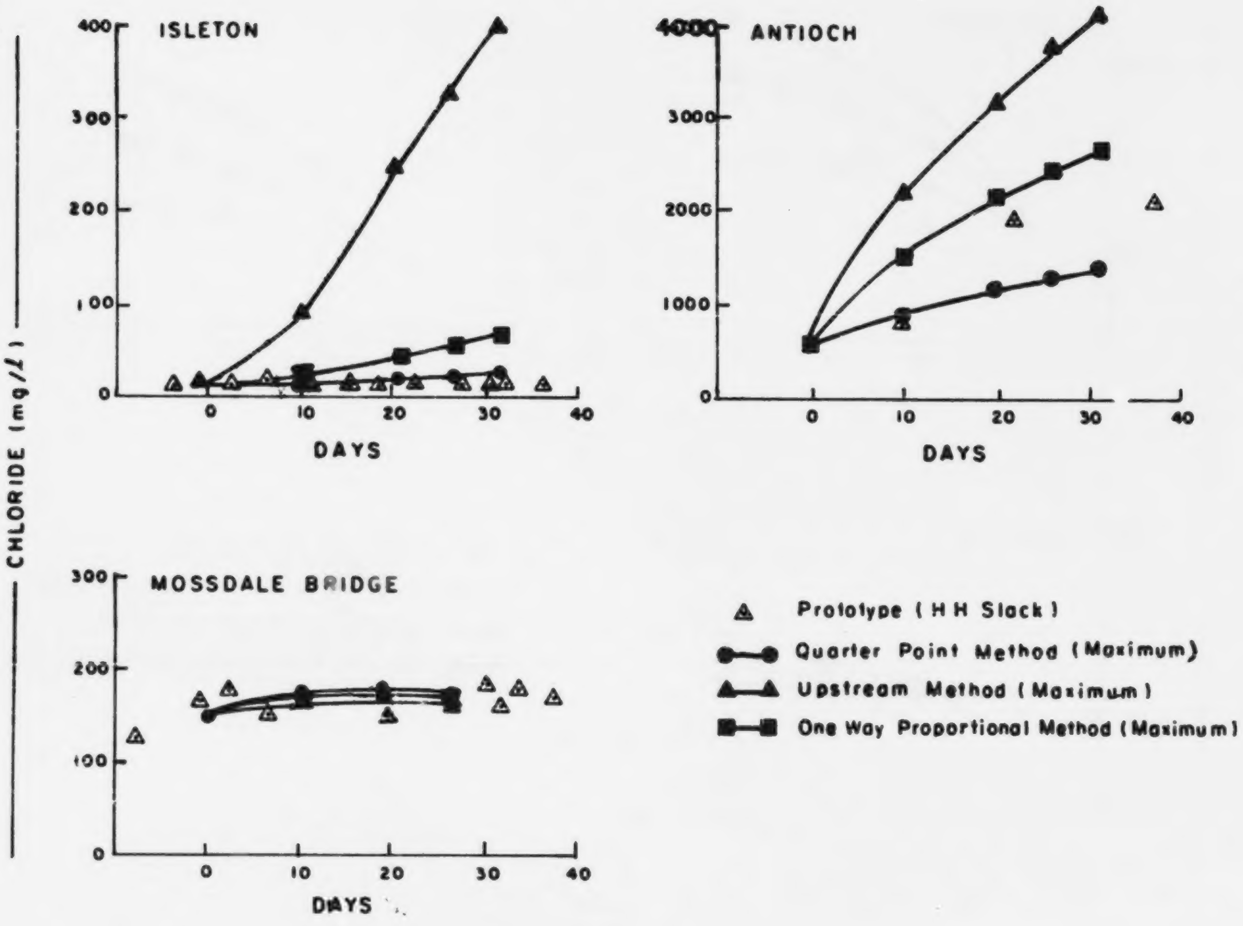


FIGURE 42. COMPARISON OF SOLUTION TECHNIQUES -- JULY 1955 CHLORIDE

## DISCUSSION OF DISCREPANCIES

Model predictions and the prototype observations differ somewhat in a number of instances for both San Francisco and San Diego Bays. These discrepancies result to a great extent from the type of comparison made. Several sources of these differences should be noted.

1. The model concentration is the average for a reach perhaps 3000 to 5000 feet in length which includes the prototype sampling location. The prototype sampling station is typically near one shore and is not necessarily representative of the cross-section, much less an extensive reach.

2. The model used a mean tide repetitively while the prototype tide was continuously changing. In areas with significant concentration gradients the tidal excursion on the day of sampling significantly influences the concentration observed.

3. The number of model junctions for which initial concentrations are known is a trivial fraction of the total number of junctions requiring initial concentrations. Vast areas of San Pablo and Suisun Bays and the Delta are without any sampling stations whatsoever and it is not possible to check estimates of initial starting conditions. Similar deficiencies exist for the San Diego Bay system. The effect of improper starting conditions is apparent over extensive areas and concentrations at the prediction points may be significantly affected.

4. The hydraulic conditions in the model are defined exactly while flow conditions in the prototype are largely unknown at any time. The use in the model of the best available estimates may nevertheless result in overall hydraulics which differ from the actual (but unknown) prototype values.

Certain of the difficulties above could probably be corrected if warranted. For instance if all daily flows and other input parameters are known the use of the actual tide for the day might be justified. Clearly the quality of information available about the prototype in either of the two systems does not now justify such operation.

The agreement between the model predictions and prototype operation to the extent that it is known is very good. It is clearly impossible at present to determine what proportion of discrepancies, if any, can be attributed to the model structure. In both systems historical prototype behavior was successfully matched without relying on any empirically derived dispersion coefficient or other factor to obtain satisfactory agreement. Since predictions do not depend on an empirically derived factor (which may be valid over a narrow flow range) reliable comparison between future alternative water quality management schemes can be made even though the future hydraulics of the system may be significantly different than any utilzied to evaluate model behavior.

## OTHER APPLICATIONS

In applications to the San Francisco and San Diego Bay systems the model has been utilized to predict the distribution of constituents which were treated as conservative (e.g., salinity, total nitrogen, tracer, etc.) and those treated as nonconservative (e.g., BOD, DO, coliform, tracer, etc.).

The mechanism for handling nonconservative constituents in the model has been extensively tested for both San Francisco and San Diego Bays and is believed to adequately represent the decay of independent constituents as well as the gross relationship between BOD and DO; however, due to a general lack of prototype data for verification, no intensive effort has been made to evaluate the efficacy of the model in this regard. Obvious shortcomings of the model, as presented herein, include: 1) the reaeration and deoxygenation rates are assumed constant, both spatially and with time, 2) temperature effects are not included, 3) algal photosynthetic and respiration effects are not included, and 4) benthic demands are not included.

Each of the above can be included in the model if warranted. In the simplest form the reaeration rate can be adjusted with changing tidal velocities and depths with time. A temperature distribution could also be specified and the reaeration and deoxygenation rates varied with temperature. Algal photosynthetic and respiration rates as well as benthic demands could also be specified spatially for a system.

In a more sophisticated approach the above effects can be an integral part of the model structure. Temperature could be included as one of the quality constituents and could thus be used to adjust temperature dependent parameters both spatially and with time. Algal populations can likewise be treated as a separate constituent with associated production and respiration rates for dissolved oxygen. The major problem in such applications lies in determining the significant parameters which affect the predictions and in defining the functional relationships between the various parameters.

Efforts to include the heat budget into the model structure for the purpose of predicting the time varying temperature distribution in an estuary have been completed by the FWQA Pacific Northwest Water Laboratory at Corvallis. This significant modeling approach will be further tested by the Northwest Regional Office in applications to the tidal portion of the Columbia River [22].

Another significant effort has been completed by the FWQA California-Pacific Basins Office in Alameda by including the effects on the dissolved oxygen budget of mechanisms such as photosynthesis and respiration by algal populations, the decay of the algal mass, and the benthic demand, in addition to the usual decay and reaeration mechanisms. Through the predictions of chlorophyll levels (and associated algal mass) the contributions to the total oxygen demand of both the carbonaceous and nitrogenous demands of the algal mass are included. This approach has been utilized to simulate the diurnal fluctuation of DO in the Klamath River in Oregon.

Five additional FWQA efforts currently (1970) underway are the application of the model to Boston Harbor by the New England Basins Office in Needham Heights, to the Yaquina Bay Estuary by the Pacific Northwest Water Laboratory, to the Potomac River Estuary through a joint effort by the Chesapeake Technical Support Laboratory in Annapolis and the FWQA Headquarters Office, to the Rappahannock River Estuary by the Middle Atlantic Regional Office, and to Port Royal Sound, South Carolina by the National Field Investigations Office in Cincinnati.

In the application to the Rappahannock Estuary the model was refined to include a time varying reaeration rate (computed by a relationship of the form of equation 36 on page 24) and a spatially varied benthic oxygen demand in the dissolved oxygen budget.

The Chesapeake Technical Support Laboratory has also included these two features in applications to the Potomac and additionally has included the nitrogenous demand as well as algal photosynthesis and respiration in the dissolved oxygen budget. That office also successfully included a second (or higher) order decay relationship to simulate phosphorus distributions in the estuary. It is anticipated that reports will be forthcoming on these applications as the new model features are refined and verified.

# PART III - USER'S MANUAL

## INTRODUCTION

The programs comprising the FWQA dynamic estuary model have been tested and run under a wide variety of hydraulic and water quality conditions and, while it is impossible to state they are completely "bug-free", there are no known difficulties. The basic model structure and logic has, for the most part, remained as developed by the contractor. The most basic changes incorporated by FWQA include the revised method of computing the velocity gradient $\partial u/\partial x$ in the hydraulic program and the implementation of the so-called quarter-point version of the quality model. The contractor concurrently incorporated the same changes in computing $\partial u/\partial x$ and has also tested and used the quarter-point version for many studies. Many additional features have been added to the model by FWQA as the needs arose. Output routines in particular were revised to provide much more flexibility in the type and quantity of output obtained.

Other features were incorporated to meet specific needs of the studies of the San Francisco Bay system, e.g. the special method of handling agricultural water use. Auxillary routines (QUALEX, ZONES, and DATAP) were added to cut down input data preparation requirements and to reduce the necessary interpretation and summary of quality outputs.

Part III of this report is intended to serve as a user's manual for implementing the programs comprising the model. The discussion will reflect certain problems and pitfalls which may arise under certain conditions or for certain types of studies.

Basic program logic, in the form of simplified flow diagrams and a brief discussion, will be presented for each program. Input data formats and deck arrangement will be included along with current program listings for reference.

The model has been executed on various computer hardware systems, including IBM 7094, CDC 6600, and IBM 360/65. The listings and discussions presented herein are as adapted to the IBM 360/65 system.

## HYDRAULIC PROGRAM (DYNHYD)

The sequence of required steps to implement the hydraulic program varies from run to run depending on the availability and adequacy of previously completed runs. A discussion of program logic, input requirements, output options, and potential implementation difficulties will be presented, followed by a detailed description of program variables, input card formats, etc.

### Flow Diagram and Program Logic

The simplified flow diagram in Figure 43 presents the sequence of steps and significant decision points for program DYNHYD and subroutine HYDEX. The number assigned to each step is for reference only and does not appear in the program. It should be relatively easy, however, to identify each step with a particular sequence of statements in the program listing.

The initial step involves reading alphanumeric data to identify the printout and the parameters for defining the size of the network (number of junctions and channels), the number of cycles (time steps) to be completed, the printout frequency, the number of junctions for which detailed printout is to be obtained, the time interval to be used in the numerical solution, the starting point on the specified input tide, and a decision variable which specifies whether a hydraulic summary of the run is to be completed, i.e., whether or not subroutine HYDEX is to be called.

The alphanumeric data to identify the run is printed as part of the heading for the output (step 2) immediately after which additional control parameters are read (step 3) which define the cycle number at which printed output is to begin, the cycle number at which storage of data on tape or disk is to begin, and the frequency (in cycles) at which restart capability is desired. These and the previously discussed control parameters are printed as part of the output heading (step 4).

Steps 5 and 6 involve reading a separate card for each junction in the network and checking to determine if the cards are in sequence. If a card is missing or if the cards are not in numerical order the job is aborted. Included on each card is the junction number, the initial head at the junction, the surface area of the junction, the inflow or withdrawal, and the numbers of the channels entering the junction. After all junction cards have been read the data are printed (step 7).

Steps 8 and 9 involve reading a separate card for each channel in the network and checking to assure that no card is missing and that all cards are in numerical sequence. Each card contains the channel number, the physical characteristics of the channel (length, width, cross-sectional area, hydraulic radius, and Manning's n), the initial

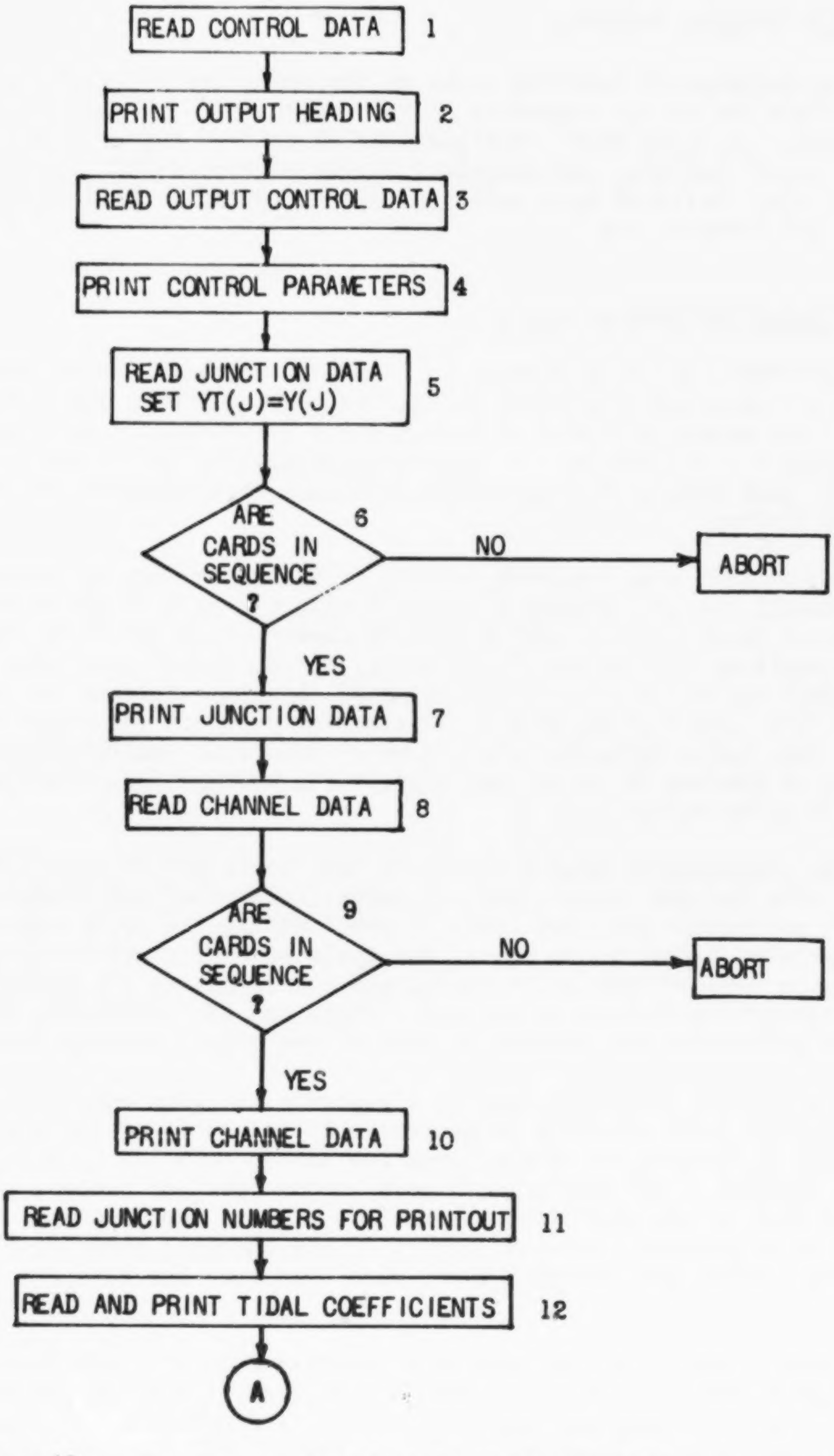


FIGURE 43. SIMPLIFIED FLOW DIAGRAM - PROGRAM DYNHYD

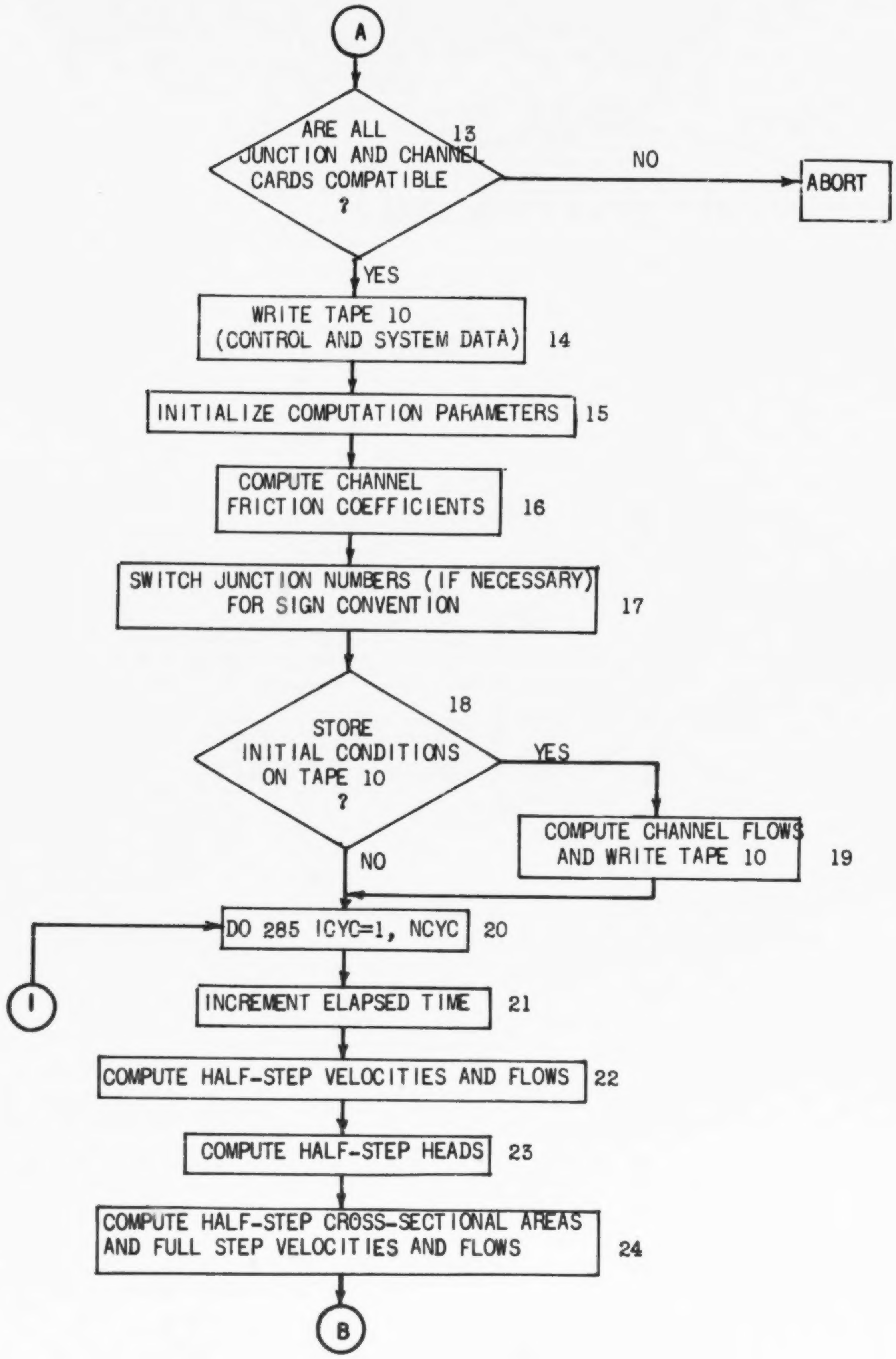

A
ARE ALL JUNCTION AND CHANNEL CARDS COMPATIBLE ?
13
NO
ABORT
YES
WRITE TAPE 10 (CONTROL AND SYSTEM DATA)
14
INITIALIZE COMPUTATION PARAMETERS
15
COMPUTE CHANNEL FRICTION COEFFICIENTS
16
SWITCH JUNCTION NUMBERS (IF NECESSARY) FOR SIGN CONVENTION
17
STORE INITIAL CONDITIONS ON TAPE 10 ?
18
YES
COMPUTE CHANNEL FLOWS AND WRITE TAPE 10
19
NO
DO 285 ICYC=1, NCYC
20
I
INCREMENT ELAPSED TIME
21
COMPUTE HALF-STEP VELOCITIES AND FLOWS
22
COMPUTE HALF-STEP HEADS
23
COMPUTE HALF-STEP CROSS-SECTIONAL AREAS AND FULL STEP VELOCITIES AND FLOWS
24
B

FIGURE 43. (Cont.)

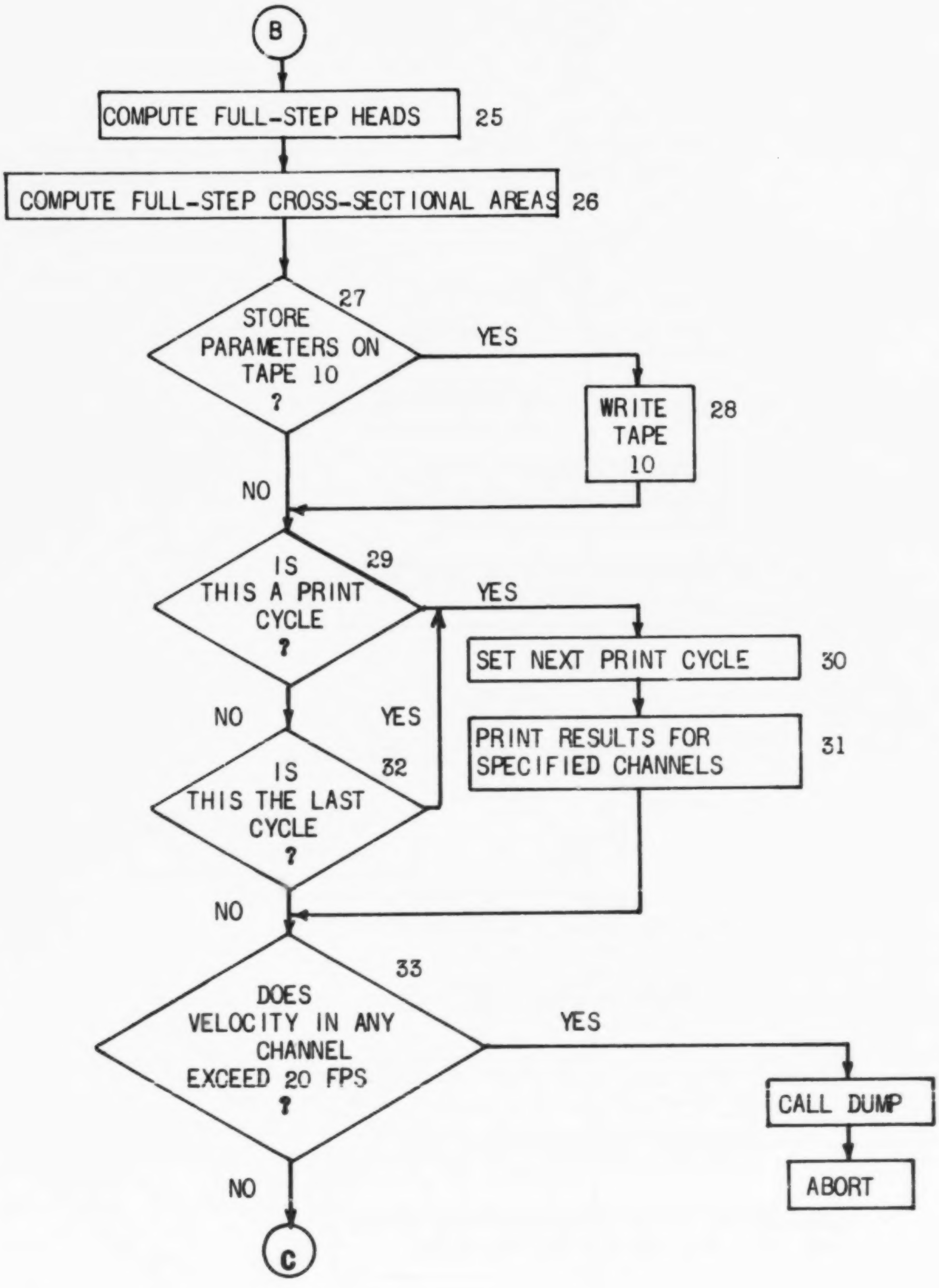


FIGURE 43 (Cont.)

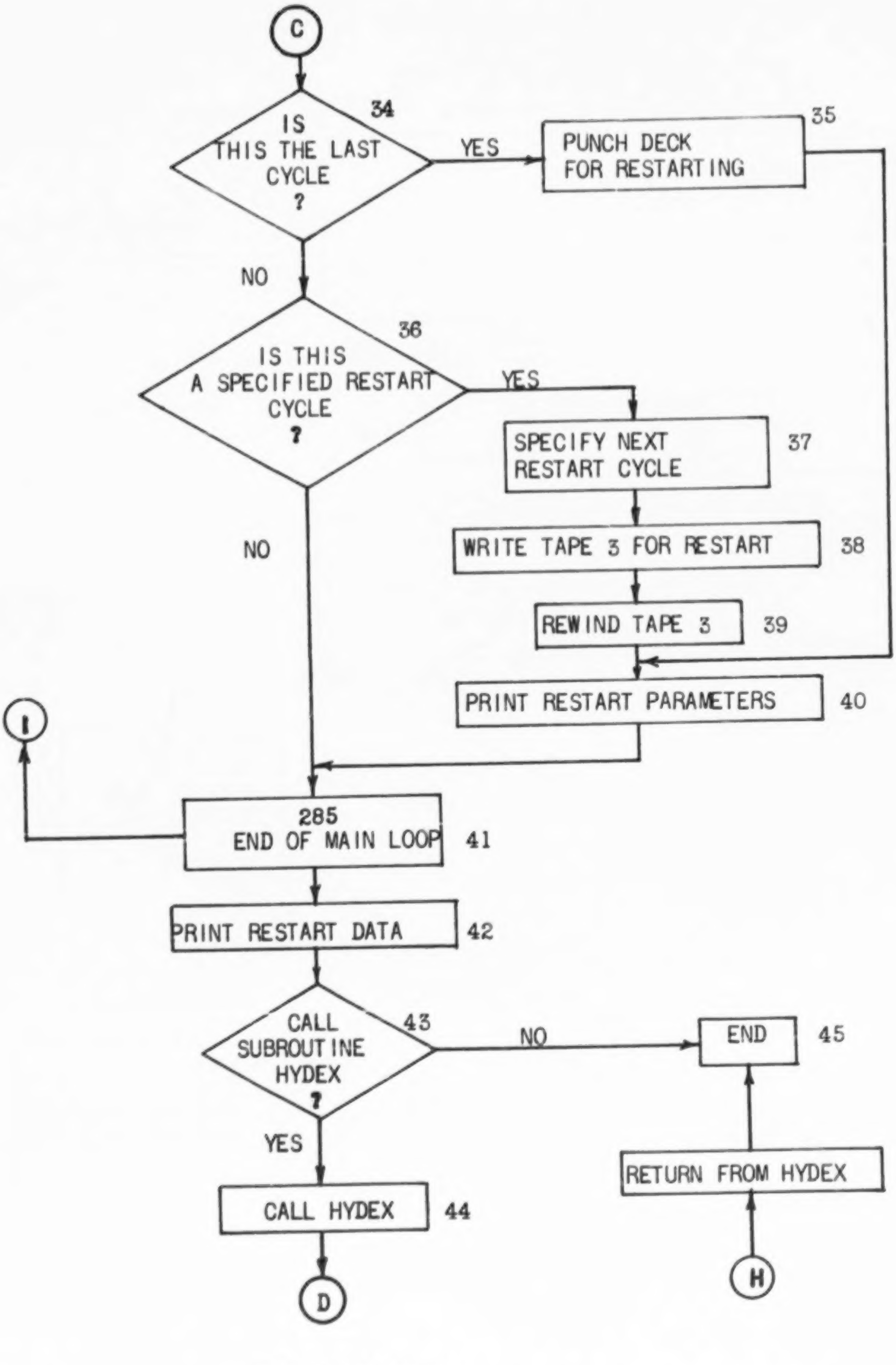


FIGURE 43 (Cont.)

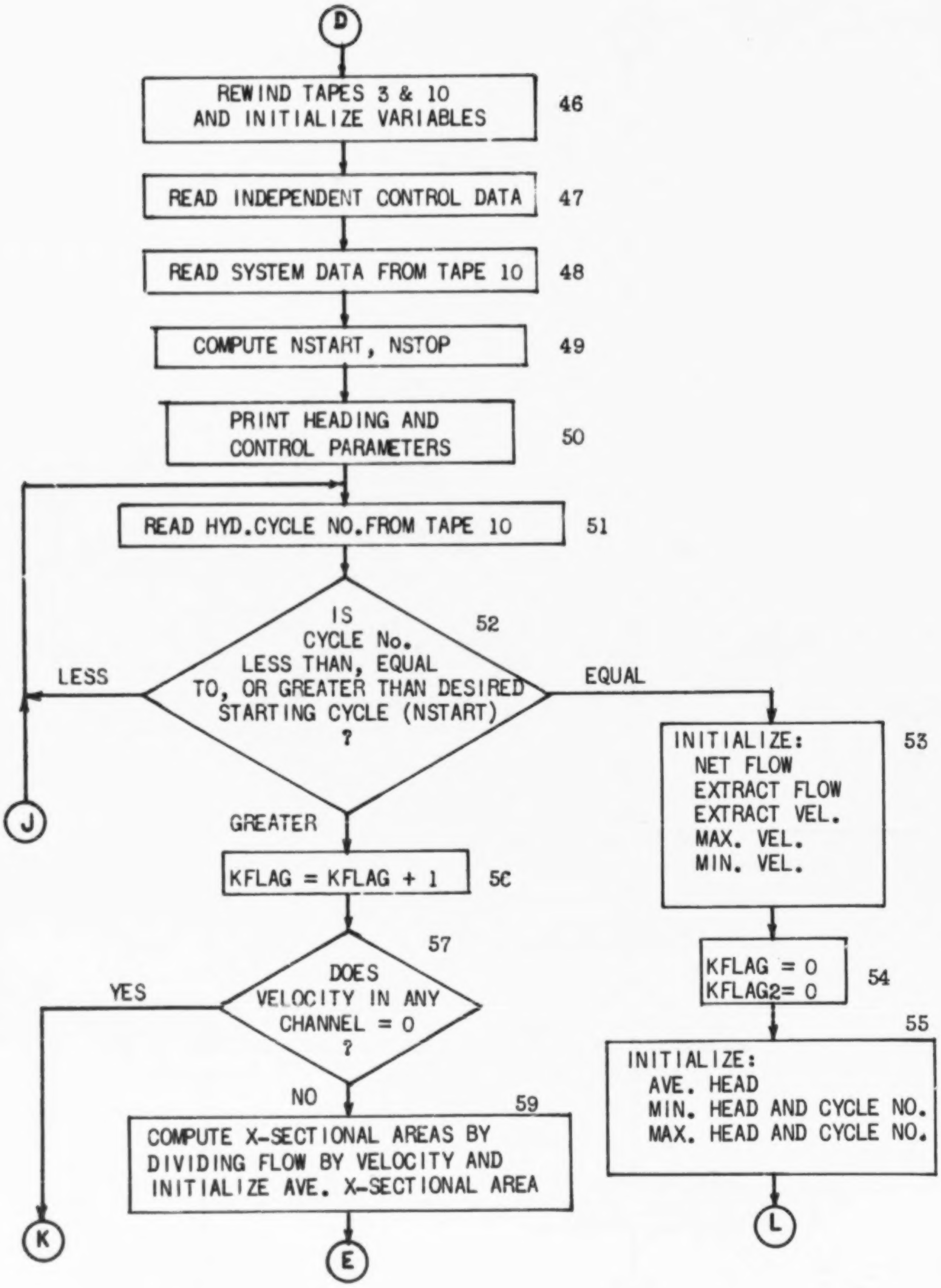

D
REWIND TAPES 3 & 10 AND INITIALIZE VARIABLES
46
READ INDEPENDENT CONTROL DATA
47
READ SYSTEM DATA FROM TAPE 10
48
COMPUTE NSTART, NSTOP
49
PRINT HEADING AND CONTROL PARAMETERS
50
READ HYD.CYCLE NO.FROM TAPE 10
51
IS CYCLE No. LESS THAN, EQUAL TO, OR GREATER THAN DESIRED STARTING CYCLE (NSTART) ?
52
LESS
EQUAL
GREATER
J
INITIALIZE: NET FLOW EXTRACT FLOW EXTRACT VEL. MAX. VEL. MIN. VEL.
53
KFLAG = KFLAG + 1
5C
KFLAG = 0 KFLAG2= 0
54
DOES VELOCITY IN ANY CHANNEL = 0 ?
57
YES
NO
INITIALIZE: AVE. HEAD MIN. HEAD AND CYCLE NO. MAX. HEAD AND CYCLE NO.
55
COMPUTE X-SECTIONAL AREAS BY DIVIDING FLOW BY VELOCITY AND INITIALIZE AVE. X-SECTIONAL AREA
59
K
E
L

FIGURE 43 (Cont.)

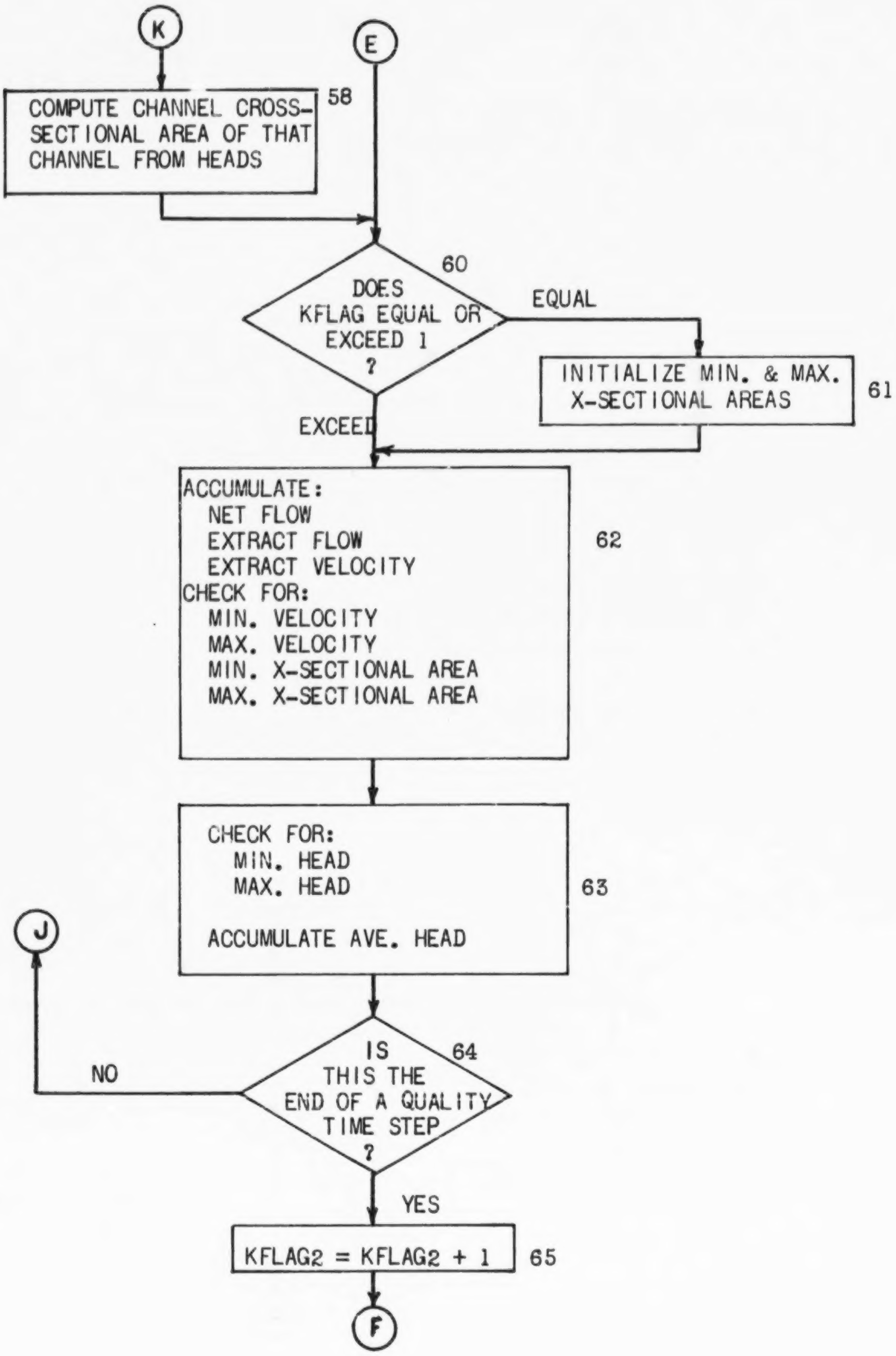


FIGURE 43 (Cont.)

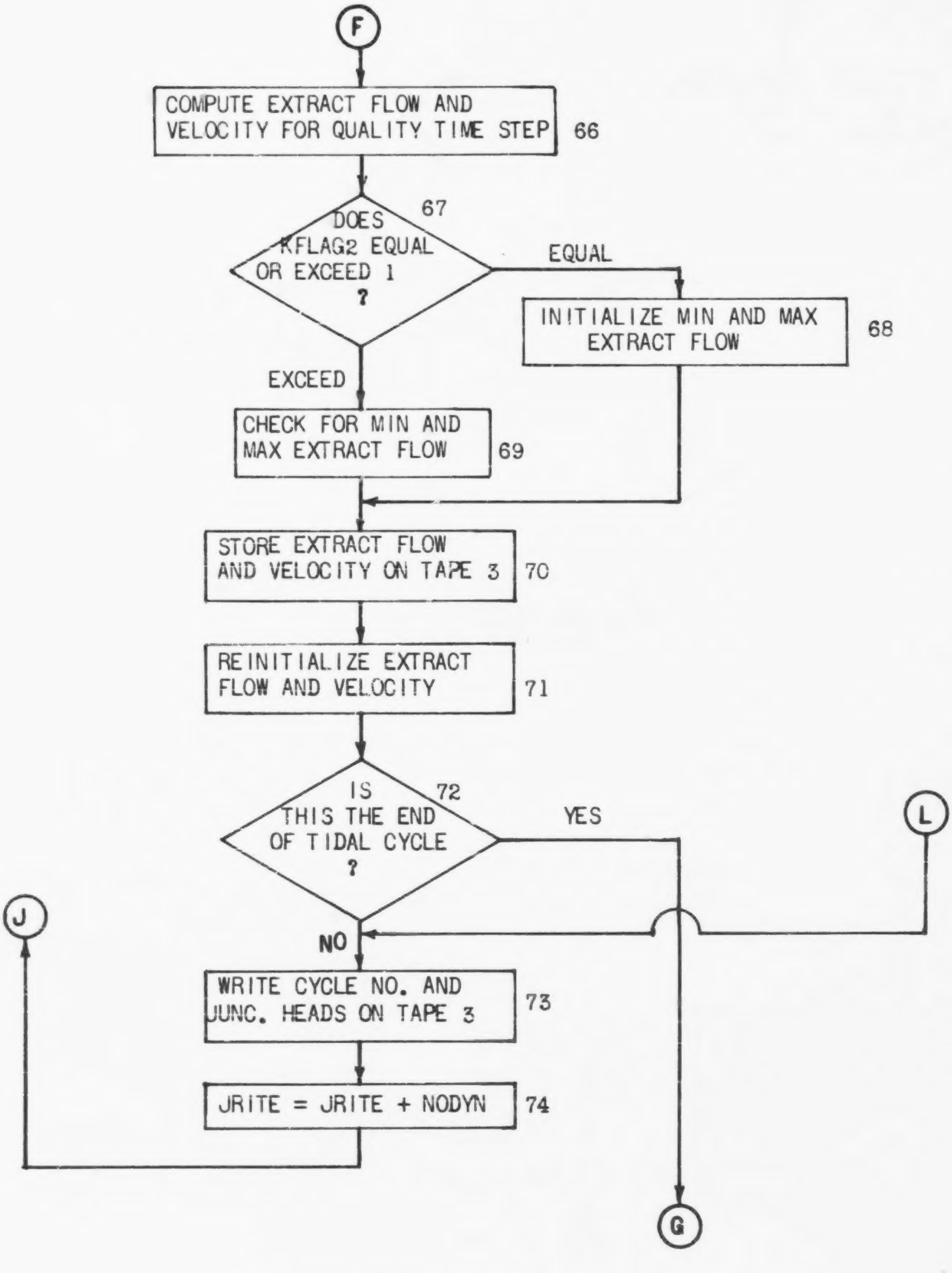

F
COMPUTE EXTRACT FLOW AND VELOCITY FOR QUALITY TIME STEP
66
DOES KFLAG2 EQUAL OR EXCEED 1 ?
67
EQUAL
INITIALIZE MIN AND MAX EXTRACT FLOW
68
EXCEED
CHECK FOR MIN AND MAX EXTRACT FLOW
69
STORE EXTRACT FLOW AND VELOCITY ON TAPE 3
70
REINITIALIZE EXTRACT FLOW AND VELOCITY
71
IS THIS THE END OF TIDAL CYCLE ?
72
YES
L
J
NO
WRITE CYCLE NO. AND JUNC. HEADS ON TAPE 3
73
JRITE = JRITE + NODYN
74
G

FIGURE **43** (Cont.)

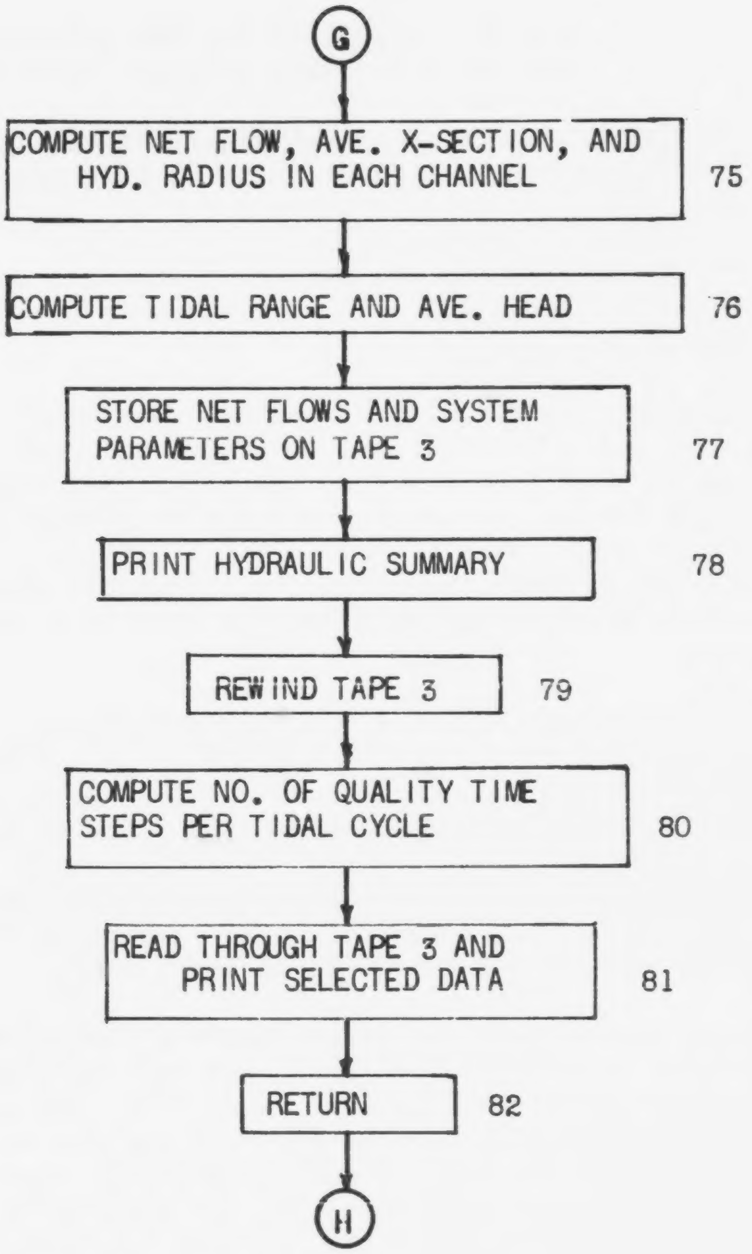

G
COMPUTE NET FLOW, AVE. X-SECTION, AND HYD. RADIUS IN EACH CHANNEL
75
COMPUTE TIDAL RANGE AND AVE. HEAD
76
STORE NET FLOWS AND SYSTEM PARAMETERS ON TAPE 3
77
PRINT HYDRAULIC SUMMARY
78
REWIND TAPE 3
79
COMPUTE NO. OF QUALITY TIME STEPS PER TIDAL CYCLE
80
READ THROUGH TAPE 3 AND PRINT SELECTED DATA
81
RETURN
82
H

FIGURE 43 (Cont.)

mean channel velocity, and the numbers of the two junctions at the ends of the channel. These data are then printed (step 10).

The list of junctions for which detailed printout is desired is read as step 11. The program is dimensioned to allow up to 50 such junction numbers.

The tidal coefficients and the period of the desired tide are read and immediately listed (step 12). The coefficients are computed in the separate program REGAN.

Step 13 involves checking the compatibility of the two separate numbering systems, i.e., that for the junctions and that for the channels. This assures that for each junction all of the entering channels are identified and for each channel the junction numbers at both ends are properly identified. Thus if a junction is listed as being connected to a given channel then that channel should also be listed as being connected to the junction. The run will abort if any discrepancies are found.

The control parameters and the junction and channel data are stored on tape 10 (step 14). This record can be maintained either as a permanent record of the run (on tape or disk) or as a temporary record available only during execution (scratch tape or disk).

Step 15 initializes various computation parameters such as the elapsed time and the restart interval and also converts the starting time and the tidal period from hours to seconds.

The friction coefficient for each channel is computed (step 16) and a check is made to determine which of the two junction numbers at each end of the channel is the smallest (step 17). The two numbers are interchanged whenever the second number is smaller than the first i.e. whenever NJUNC(N,2) is smaller than NJUNC(N,1). This switch is necessary for the sign convention utilized for specifying the direction of flow in a channel. After completion of step 17, NJUNC(N,1) will always be smaller than NJUNC(N,2).

Normally the initial junction heads and channel velocities and flows need not be stored on tape 10 (steps 18 and 19). Only if the run is a continuation of a previous run is it desirable to record the initial conditions (in effect the initial conditions become cycle zero).

The main computation loop begins at step 20. After incrementing the elapsed time (step 21), the velocity in each channel is projected to the middle of the time step utilizing the equation of motion discussed in Part I. This projection (step 22) is completed independently for each channel in the network during each time step. The half-step velocities are utilized to compute the half-step flows (product of the velocity and cross-sectional area) and these in turn are used to adjust the junction heads for the half time step (step 23). This is accomplished by computing the net flow into (or out of) a junction from all sources and adjusting the volume (head) accordingly. These new junction heads are then used to adjust the channel cross-sectional areas to the half time step and also to project the channel velocities (and flows) to the end of the full time step (step 24). The head at each junction is then computed for the full time step (step 25) and the cross-sectional area of each channel adjusted (step 26) by the product of its width and the average change in head at both ends of the channel (channel widths are assumed constant).

The junction heads and channel velocities and flows are stored on tape 10 if the cycle number is equal to or greater than a specified value (steps 27 and 28). A check is then made to determine whether the predictions for the current cycle are to be printed (step 29). If the current cycle is a print cycle the next print cycle is set (step 30) and printout is obtained for the specified junctions (step 31). If the current cycle is not a specified print cycle printout will still be obtained if the cycle is the last cycle of the run (step 32), i.e., printout is always obtained for the last computation cycle.

The computed velocities in each channel are checked for reasonableness (step 33). If the absolute value of the velocity in any channel exceeds 20 feet per second (indicating computational instability) the run is aborted. A core dump is obtained for certain junction and channel parameters to aid in determining the cause of the instability.

Prior to recycling to the start of the main computation loop a check is made to determine whether the current cycle is the last computation cycle (step 34). If it is the last cycle the current junction and channel parameters are punched into a deck with a format which can be used as an input deck in the event it is necessary or desirable to extend the run (step 35). Prior to the last computation cycle a check is made to determine whether the current cycle is a specified restart cycle (step 36). At each specified restart cycle (prior to the final computation cycle) the current junction and channel parameters are stored on tape 3 (step 38). The tape is then rewound (step 39) and if computations proceed to the next restart cycle the tape is updated with the current parameters. After each write command pertinent restart parameters are printed to provide information for restarting (step 40). Following the completion of the specified number of computation cycles for the main loop (step 41) the final status of the run is printed for all junctions and channels (step 42). A check is then made as to whether subroutine HYDEX is to be called (step 43). Except for certain test runs subroutine HYDEX would normally be called to summarize the run.

The initial step (step 46) in the subroutine is to rewind both the hydraulic tape (tape 10) and the extract tape (tape 3). Up to this point in overall execution tape 3 has been utilized as a restart device in the event of premature termination of execution. Under such condtions subroutine HYDEX would never be called and tape 3 would have on it the necessary data for restarting the run from the cycle at which the tape had last been written. If execution is not terminated prematurely and subroutine HYDEX is called then the ending hydraulic conditions have already been punched into a restart deck and the record on tape 3 is no longer needed. Thus the rewind command in subroutine HYDEX readies the tape for its new use as the storage device for the extracted hydraulic parameters (which is used as input to the quality program). Tape 3 thus serves a dual purpose during execution of the hydraulic program.

In addition to the system information stored on tape 10 two additional cards of alphanumeric input are read in subroutine HYDEX which are printed as part of the heading of the output. Also the time interval which will be utilized in the quality solution is specified (step 47) as some whole multiple of the time interval used in the hydraulic solution (NODYN). For example if the hydraulic time step is 100 seconds and the desired quality time step is one-half hour (1800 seconds) NODYN would be specified as 18. Following the specifcation of the independent control data the system data stored on tape 10 during execution of the hydraulic program is read (step 48).

The hydraulic summary provided by subroutine HYDEX is for a complete tidal cycle; therefore it is necessary to compute the cycle numbers in the hydraulic solution at which the last full tidal cycle began and ended (step 49). In some cases the data on tape 10 may have been limited to exactly one tidal cycle. In others more than a full tidal cycle may have been stored on the tape. Because the hydraulic solution converges to a dynamic steady state condition the predictions only over the last full tidal cycle should be used for the summary as they are the most representative of a steady state condition.

A heading for the output from the subroutine is provided to identify the run (step 50).

Following the initial read command for tape 10 in which the system data were read (step 48) the tape is positioned at the start of the continuous record of predictions for each hydraulic cycle (time step). At step 51, which starts the main computation loop in subroutine HYDEX, the value for the first cycle number stored on tape 10 is read, along with the values of hydraulic parameters predicted for that time step. A check is then made to determine whether the cycle read is less than, equal to, or greater than the cycle number computed previously which specifies the desired starting point on the tape (NSTART). If the number is less than NSTART the next cycle and associated hydraulic parameters are read from tape 10 (step 51) and the check at step 52 made again. This continues until the cycle read equals NSTART at which point the summary begins (step 53). Several separate summaries are initialized in this step including the mean or net flow in each channel over the entire tidal cycle, the mean velocity and flow in each channel during the initial quality time step, and the minimum and maximum velocities in each channel over the full tidal cycle. For the net flow computation the values for each cycle (time step) are accumulated over the entire tidal cycle and the accumulated total divided by the total number of time steps comprising the tidal cycle. Similarly the means for the initial quality time step are computed by accumulating the values for each individual hydraulic cycle over the full quality time step and the accumulated total divided by the number of hydraulic cycles per quality cycle (NODYN).

If the hydraulic solution has, in fact, reached a dynamic steady state condition the values predicted for the hydraulic parameters at the initial cycle (NSTART) will be identical to those predicted for the final time step of the tidal cycle (NSTOP). Normally however, the solution will not have reached true steady state and slight differences between the starting and ending points on the tidal cycle will exist. Rather than use one set of values or the other in computing the averages over the tidal cycle, both are used, but each is assigned a weight of one-half to average out the difference.

To initialize the determination of the minimum and maximum values for the velocity in each channel each is initially assumed equal to the velocities existing for the initial cycle. At each successive cycle these values will then be compared to the current values and updated as required.

Two internal counters are initialized (step 54) which will be utilized later to flag the beginning of other special summaries. The determination of the minimum and maximum heads at each junction is initialized (step 55) by equating both to the head at the initial cycle. Following the completion of the initial cycle (step 55) control passes to step 73 where the initial cycle number (NSTART) and the heads at each junction for that cycle are stored on tape 3. The cycle number at which the next quality time step begins is determined (step 74) and control passes back to step 51 to read the parameters for the next hydraulic time step. Steps 53 through 55 will be completed only once, i.e., for the initial time step (NSTART). For all subsequent cycles control passes to step 56 where the computations initialized in steps 53 through 55 are continued.

At the start of each cycle (except the initial one) the counter KFLAG is incremented by one (step 56).

Included in the summary of the hydraulic run is the determination of the mean, maximum and minimum cross-sectional areas of each channel over the full tidal cycle. The values for the cross-sectional area were not stored on tape 10 for each time step; however they can be regenerated at this point by dividing the channel flow by the velocity. To avoid the problem associated with division by zero a check for zero velocity is made (step 57). For any channel in which the velocity is zero the cross-sectional area is computed from the heads existing at both ends of the channel (step 58). Otherwise the channel cross-sectional area is computed by dividing the flow by the velocity (step 59). In both cases the cross-sectional area for each channel is added to the total accumulated previously which will be used to determine the average over the full tidal cycle.

A check is made (step 60) to determine if KFLAG is equal to or exceeds one. KFLAG will equal one only the first time through this step, indicating that the computations for determining the minimum and maximum cross-sectional areas need to be initialized (step 61). For all subsequent cycles step 61 will be bypassed.

The flow in each channel is added to the accumulated totals for the net tidal cycle flow (QNET) and to the extract flow (QEXT) for the quality time step. The velocity in each channel is similarly added to the accumulated total for the extract velocity (VEXT) for the quality time step. The maximum and minimum values previously established for the channel velocities and cross-sectional areas are checked against the current values and are updated as necessary. These accumulations and comparisons are represented as step 62 in the flow diagram.

Step 63 involves a similar accumulation for determining the average head over the tidal cycle and a comparison and updating of the minimum and maximum heads established previously.

Following the above computations for each hydraulic cycle read from tape 10 a check is made (step 64) to determine whether the end of a quality time step has been reached (occurs each NODYN cycles). If not the next cycle is read from tape 10 (step 51) and the above sequence repeated. At the completion of each NODYN hydraulic cycles KFLAG2 is incremented by one (step 65) and the extract flow (QEXT) and velocity (VEXT) for the quality time step are determined (step 66) by dividing the accumulated totals for each by the number of hydraulic time steps (NODYN). Following the initial quality time step KFLAG2 will equal one (step 67) which triggers the initialization of the computations for determining the minimum and maximum values of the extracted flows (QEXT). For all subsequent cycles the previously established minimum and maximum values for QEXT are compared to the current values and updated as required. The values for the extracted channel flows and velocities are then stored on tape 3 (step 70) for later input to the quality program. The accumulated totals for the extract flows and velocities are then reinitialized (step 71) for the next quality time step.

After completing the extract for each quality time step a check is made to determine if the last cycle on tape 10 (NSTOP) has been reached. If not the current value of the hydraulic cycle number and the head at each junction is stored on tape 3 to mark the start of a new quality time step (step 73). The cycle number identifying the start of the subsequent quality time step is computed (step 74), followed by the next reading of tape 10 (step 51).

When computations for the last cycle (NSTOP) have been completed the net flow (QNET) and the average cross-sectional area (ARAVE) in each channel are computed by dividing the accumulated totals for these parameters by the total number of hydraulic time steps in the full tidal cycle (step 75). The mean channel depth (hydraulic radius) is computed by dividing the average cross-sectional area by the channel width as part of step 75.

The tidal range at each junction is computed as the difference between the maximum and minimum heads and the average head at each junction is computed by dividing the accumulated total for the parameter by the total number of time steps (step 76).

The net flow in each channel and pertinent system parameters are stored on tape 3 (step 77). These parameters are stored at the end of tape 3 rather than the beginning to avoid the necessity of having to read over these data each time the tape is read during execution of the quality program. Hydraulic parameters for only a single tidal cycle are stored on tape 3; hence for quality simulations of greater duration than one tidal cycle the tape must be rewound and the values used again. This repeated use of the hydraulic parameters is continued as necessary to complete a specified number of cycles.

A printed summary of the net flows and the minimum and maximum velocities and flows in each channel is obtained along with the minimum, maximum, and average channel cross-sectional areas (step 78). A similar summary of the heads at each junction is also provided.

Tape 3 is then rewound (step 79) and the number of quality time steps comprising a full tidal cycle is computed (step 80). Tape 3 is then read completely through (step 81) and each hydraulic cycle number which had been stored on the tape is printed along with the corresponding head at junction number one and the extracted flow in channels number one and two. This list of data provides a convenient check on the data stored on the tape.

At the completion of subroutine HYDEX control returns to the main program (step 82) and the execution terminates (step 45).

## Input Requirements

The input requirements for the hydraulic program can vary tremendously from run to run depending on the uniqueness of the conditions to be simulated. The data requirements for the initial application of the model to a new system are considerable. The system must be represented by a network and the physical parameters of each channel and junction element determined. The most demanding of these inputs are the channel cross-sectional areas and the junction heads. The specified junction heads establish the water surface elevation throughout the network and it is imperative that the cross-sectional areas assigned to each channel correspond to those heads. The heads throughout the system are referenced to a common, horizontal datum. Channel depths can usually be obtained with sufficient accuracy from the soundings printed on navigation charts published by the Coast and Geodetic Survey. Unfortunately, however, these soundings are normally representative of a mean low water condition at the point of the sounding and are not referenced to a common datum. It is therefore necessary to establish the relationship between low water at each point in the system and the horizontal datum selected for the model. Such relationships may be available for certain points in the system, such as at tidal stage recorders or at other points where tidal predictions are made. River bed profiles may also be available from which such relationships could be determined. Once the relationships between the junction heads and channel cross-sectional areas have been properly established for a given system they should never have to be reestablished because the model program maintains the proper relationship at all times during execution. It is usually most expeditious to specify a constant value for each of the junction heads (assumes a horizontal water surface) in preparing the data for the first time and then adjust the channel depths (and cross-sectional areas) accordingly. While it might be desirable, in order to save computation time, to specify the initial heads at each junction in such a manner that the water surface profile is more representative of one which actually occurs in the prototype, such an effort is probably not warranted. Unless extensive tide data are available to establish the water surface elevation at many points in the system for a given instant in time a great deal of interpolation between points will be required. It is doubtful whether the execution time saved by such a procedure warrants the additional effort involved.

A similar argument holds for the specification of the initial velocity in each channel. Normally data in sufficient quantity will not be available to establish a detailed velocity pattern for the entire system at a given instant in time. Therefore a constant initial velocity (such as zero) is assumed throughout the system. Thus for the initial run on a new system the total mass of water might initially be assumed to be at rest with a horizontal water surface. As the solution progresses it will converge to the appropriate dynamic steady state condition wherein the head at each junction and the velocity and flow in each channel are repeated with a frequency equal to the period of the specified tide.

For all runs subsequent to the initial run the input data requirements are greatly reduced. Many of the physical parameters such as channel lengths and widths and the surface area of each junction remain constant during execution and therefore do not vary between runs.

Similarly the network layout and numbering systems generally remain constant. Only if physical changes in the prototype (real or proposed) are to be modeled is it necessary to change the model network. Even then the changes normally affect only a small fraction of the total number of junction and channel elements.

The initial junction heads and channel velocities can be obtained directly from the restart deck punched at the end of any previous hydraulic run. Although the specified tidal conditions for the two runs may not be identical it is usually possible to choose the starting point on the new tide to correspond closely to the ending tidal elevations on the previous tide. Care must be exercised to assure that the tidal phase as well as elevation is matched at the boundary so that the ending conditions from the previous run are appropriate throughout the system e.g. if the ending elevation at the boundary is at a certain level and rising, the starting point on the new tide should be as close as possible to that elevation and on a rising portion of the curve. If this can be accomplished the ending channel velocities from the previous run should also provide excellent starting conditions for the new run.

Other than the control data, which will be unique for each run, the only inputs that may need to be respecified from run to run are the tidal condition imposed at the boundary and the specified accretion or depletion at each junction in the system. Frequently, however, only a small number of these inputs need be changed. For example when evaluating and comparing various waste disposal schemes in an estuary the tidal conditions and basic hydrologic inputs may remain the same for all runs with only the key waste discharge inputs changing (either in location or in quantity) from run to run. For those cases wherein different tidal conditions and/or different hydrologic inputs are to be specified the two auxillary programs REGAN and DATAP are available to aid in the preparation of these data.

## Output Options and Control

Three forms of output can be obtained from the hydraulic program: (1) printed output which provides a written record of the status of the run and a summary at the end of the run, (2) a permanent record of the run on tape (one or two tapes) and (3) punched output in the form of a restart deck.

Printed output is controlled by three separate parameters, NPRT, NOPRT, and IPRT. NPRT specifies the interval (in time steps) between printouts. Generally output at half-hourly intervals is sufficient to define the dynamic character of the predictions over the tidal cycle. For a given time interval, DELT, (for example 100 seconds) the specified number of time steps between printout, NPRT, (for example 18) defines the print interval (one-half hour). NOPRT defines the number of junctions for which printout is to be obtained. For each of the NOPRT junctions the head predicted during the time step is printed along with the velocity and flow in each of the channels entering that junction. Output of this form is illustrated on pages 196 through 198 in the Appendix. The control parameter IPRT defines the initial cycle number for which printout is to be obtained. Printout is obtained beginning at cycle number IPRT and at each NPRT cycles thereafter. Printout is automatically obtained for the last cycle of the run regardless of whether it coincides with a normal print cycle. In many cases computations must proceed for three or four tidal cycles before the solution converges to a steady state condition. In such cases printed output can be limited to only the last complete tidal cycle by the appropriate specification of IPRT. IPRT can also be specified to assure that printout begins at a convenient reference point on the time scale (such as precisely on the hour or half-hour) regardless of the starting point on the input tides (as specified by TZERO).

There is no specific control over printout obtained from subroutine HYDEX. If the subroutine is called a printout of the hydraulic summary is provided. An example of the output obtained from HYDEX is provided on pages 201 through 203 in the Appendix.

Although it is not necessary to maintain a permanent record of the hydraulic run (tape 10) it is necessary that the predictions for every time step over a complete tidal cycle be stored on tape 10 during execution in order that the hydraulic extract tape (tape 3) can be prepared. If a permanent record of the run is not desired tape 10 can be specified as either a scratch tape or disk. A permanent record of the extracted tape (tape 3) must be established (either or magnetic tape, disk pack, or data cell) to provide the required hydraulic input to the quality program.

It may be desirable to also establish tape 10 as a permanent (or semi-permanent) record of the run for any of three reasons: 1) If tape 10 is treated as a scratch device and execution is prematurely terminated for any reason (such as time estimate, lines of output, etc.) the entire run might have to be repeated in order to create the extract tape, 2) if any record on the extract tape is damaged or destroyed the entire tape can be re-created from the hydraulic record (using subroutine HYDEX as a separate program), and 3) if it is desired to utilize a quality time step other than that for which the hydraulic extract tape was originally created the hydrualic record can be re-extracted utilizing a different time step (again using subroutine HYDEX as a separate program). Whether or not the record on tape 10 should be maintained as a permanent record depends on the relative cost of re-creating the run and the purchase and storage cost for magnetic tape, disk pack, or data cell. Such a comparison will vary from system to system and is largely dependent on the size of the network (number of junctions and channels). For large systems which require significant execution time a permanent record on tape 10 might eliminate the necessity of a costly rerun.

The length (in hydraulic cycles) of the record stored on tape 10 is controlled by the input variable IWRTE. The record begins at cycle IWRTE and continues for every cycle thereafter. If the specified duration of a run exceeds one full tidal cycle IWRTE can equal the cycle at which the last full tidal cycle begins.

The ending junction heads and the final channel velocities and cross-sectional areas computed in the run are punched into a deck which can be used to extend the run or which can be used as the starting conditions for a different hydraulic run.

## Sign Convention

Two different sign conventions are utilized in the model. One is utilized to describe flow into or out of a junction and the other to define the direction of flow in a channel. When referring to a junction any flow entering the junction is assigned a negative value and any flow leaving the junction a positive value. This convention holds regardless of whether the flow is from an external source e.g. an inflow or waste discharge or from an internal source, i.e., from an adjacent junction.

When considering a channel element the flow (and velocity) is assigned a negative value whenever the flow is from the end with the higher of the two junction numbers to the end with the lower of the two numbers and is assigned a positive value when the flow is in the opposite direction. These sign conventions can be illustrated by observing the sample output on pages 196 through 201 in the Appendix. For example on page 197 the printout for junction number 16 indicates a negative flow in channel 17 and positive flows in channels 18, 19, and 21. Since these flows are in reference to junction 16 these signs indicate that the flow in channel 17 is entering junction 16 and the flows in the remaining channels are leaving the junction. It should be pointed out that the signs associated with the velocities and flows listed for channels 17, 18, 19, and 21 on page 197 have been converted to the sign convention for the junctions strictly for convenience in interpreting the output. The signs should not be interpreted to indicate a negative or positive flow in terms of the sign convention used for the channels. For example on page 200 it can be noted that channel number 17 connects junctions 15 and 16. Since the printout on page 197 indicated the flow in channel 17 was flowing into junction 16 it is obvious that the flow direction is from junction 15 toward junction 16. Thus, using the channel sign convention, the flow is positive. The negative sign printed on page 197 merely allows the flow direction in channel 17 to be determined without the need to determine the junction numbers at each end.

## Interpretation of Output

At the conclusion of each hydraulic run it is important that a determination be made as to whether the run reached a steady state condition. It is difficult to estimate a priori how long a solution must be continued to produce the required full tidal cycle of predictions representative of a steady state condition. If good starting conditions are available the solution may converge after a few hours (simulated time) such that the total simulated time only slightly exceeds the tidal period. With poorer starting conditions the solution may have to be continued for three or more full tidal cycles in order that the last full tidal cycle of the run be at steady state.

As a hydraulic solution progresses the heads predicted for each time step over the tidal cycle converge to unique values for each junction in the network. The predicted channel flows also converge to unique values which are repeated each tidal cycle. Precise repetition of these parameters is not required; however, the degree of precision required is difficult to define and may vary between systems. For example if a system is represented by a relatively course network (such that the junction surface areas are large) a small variation in head (e.g. 0.01 feet) can represent a significant volume (which in turn can represent a significant change in flow). It can thus be erroneous to conclude a solution is at steady state solely on the basis of comparing the predicted heads at those junctions for which printout is obtained. A more reliable test is to determine whether the net tidal cycle flow (the average over the entire tidal cycle) has converged to a predetermined value in selected channels. The combined steady state net flow through all the channels cut by a plane which passes completely through the network is equal to the algebraic summation of all the inflows, waste water discharges, diversions, exports, etc. assigned to those junctions on the upstream side of the plane.

The importance of the determination for a steady state hydraulic solution lies not so much with a necessity to accurately define the net flow but with the fact that the ultimate distribution of a quality constituent can be quite dependent on the net seaward (or landward) flow. When comparing alternative waste disposal schemes or when determining the freshwater outflow required to prevent salinity incursion it is important that the model prediction has converged to the specified net flow in order that proper conclusions be drawn.

## Potential Implementation Difficulties

The difficulties associated with implementing the hydraulic program generally fall into one of two categories, i.e., either 1) the solution becomes unstable, or 2) execution terminates prematurely. A third problem, involving storage limitations on magnetic tape, may arise for large networks or on certain computer systems. As will be discussed later in this section, this problem can be prevented (once discovered) by certain programming changes and should not be of a recurring nature.

Execution of the hydraulic program is terminated if the velocity in any channel exceeds twenty feet per second, indicating an unstable (diverging) solution. This problem generally arises most frequently during the initial applications of the model to a new system. It can arise, however, even after many successful previous applications, particularly if the hydraulic conditions are significantly different from any previously considered.

An unstable solution usually results from one or more of the following conditions: 1) one or more inputs have been improperly specified (keypunching error, etc.), 2) the stability criterion is violated for a certain channel (indicating the channel length should be increased or the time step decreased), 3) a junction surface area is not properly represented (occurs frequently at dead end channels), or 4) a junction volume is not properly represented (occurs either at dead end channels or in areas such as tide flats where the depth at low tide may be zero). Under such conditions unrealistic hydraulic gradients can be created which result in excessive velocities. If execution is terminated for this reason a core dump is obtained which gives the values of the junction heads, channel cross-sectional areas, and channel flows. These values can be helpful in determining the cause of the instability.

The instability can usually be eliminated at dead end channels by increasing the surface area of the end junction somewhat above that indicated on published maps or charts to eliminate wave reflection caused by the abrupt channel ending. There may be little, if any, wave reflections in the prototype since a real channel rarely ends as abruptly as represented by the model network.

Similarly in areas such as tide flats where the depth at low tide may reach zero the instability can normally be corrected by increasing the depths of the peripheral channels slightly. As programmed the model does not adjust the water surface area of a junction as the water rises and falls. There is also no provision for allowing a junction to "run dry" (reach zero depth). The model network parameters in these areas may be specified to compensate for these shortcomings however. The channel depths and the surface area assigned to the junctions are representative of the mean tide level such that at low tide the junction volumes are slightly over-represented and at high tide under-represented.

Premature termination of program execution due to improper estimates of execution time or lines of output can result in costly reruns unless built-in restart options are exercised. The specification of the frequency with which restart capability is desired is not difficult; however, in the event it becomes necessary to restart a run (or extend a previous run) it is very important that execution begin precisely at the point the previous execution was terminated. This requires the proper specification of the initial time, TZERO. At the completion of each update on tape 3 and also after punching the restart deck at the end of a run the value of TZERO for restarting is printed. It is printed to seven places beyond the decimal point to provide the necessary accuracy for restarting the computations at the point they were discontinued.

It is possible to execute the hydraulic program utilizing a scratch disk rather than magnetic tape for unit 10 since the records stored on this unit are used only during execution of subroutine HYDEX to generate a permanent record of extracted hydraulic parameters on magnetic tape or disk (unit 3) for input to the quality program. Creating a permanent record for unit 10 (on tape or disk) does, however, provide a backup record which can be used to re-create the extract tape without re-running the entire hydraulic run. Such a permanent record can also be utilized to extract the hydraulic parameters with different time steps (which may be desirable during the early application and testing of the quality model).

For systems represented by a network with a large number of junctions and channels the length of the record to be stored on tape 10 may exceed the maximum limit for a magnetic tape, i.e., the tape may be completely filled. For such cases it may be necessary to reprogram the hydraulic program and the extract subroutine to accommodate two tapes rather than one. The reprogramming effort is largely tied with specification of the starting and stopping points on each tape.

## Execution Time

Typical execution times for the hydraulic program are summarized in Table 6. The execution time is dependent on the computer used (and on the accounting procedure utilized), the size of the network, the time step utilized, the duration of the run, and the amount of output specified.

TABLE 6. EXECUTION TIMES FOR HYDRAULIC MODEL

| Size of Network | | Time Step | Length of Run | Execution Time | Computer |
|---|---|---|---|---|---|
| Junctions | Channels | (seconds) | (hours) | (Minutes) | Used |
| 112 | 170 | 50 | 37.5 | 5 | CDC 6600 |
| 112 | 170 | 50 | 50 | 8 | CDC 6600 |
| 112 | 170 | 50 | 25 | 8 | IBM 360/65 |
| 247 | 306 | 75 | 12.5 | 4 | CDC 6600 |
| 247 | 306 | 75 | 12.5 | 7 | IBM 360/65 |
| 247 | 306 | 75 | 25.0 | 13 | IBM 360/65 |
| 830 | 1050 | 100 | 12.5 | 8 | CDC 6600 |
| 830 | 1050 | 100 | 25 | 12 | CDC 6600 |
| 830 | 1050 | 100 | 37.5 | 15 | CDC 6600 |
| 830 | 1050 | 100 | 49 | 23 | CDC 6600 |

## Description and Format of Program Inputs (DYNHYD)

In the following description defining the format of the input data deck required to execute program DYNHYD the symbol:

| | |
|---|---|
| * | denotes that a series of cards as described may be required. |
| a | denotes that the card or series of cards may not be required. |
| R | indicates "right hand justified," i.e., any quantity so described must appear as far as possible to the right of its data field. |
| . | indicates a decimal point must appear in the field. |
| R. | indicates that the value is right hand justified but may have a decimal point to override the programmed decimal point. |
| .<br>.<br>.<br>. | indicates the continuation of the same format on a card. |
| .... | indicates the start of a new card. |

| Card | Column | Name | Description |
|---|---|---|---|
| 1 | 1-80 | ALPHA(I) | Alphanumeric identifier -- printed as first line of output (up to 80 characters). I = 1,20 with A4 format. |
| 2 | 1-80 | ALPHA(I) | Alphanumeric identifier -- printed as second line of output (up to 80 characters). I = 21,40 with A4 format. |
| 3 | 1-5R | NJ | Total number of junctions in system. |
| | 6-10R | NC | Total number of channels in system. |
| | 11-15R | NCYC | Total number of time steps (cycles) to be completed. |
| | 16-20R | NPRT | Number of time steps between printouts. Normally specified to give output at one-half or hourly frequencies. |
| | 21-25R | NOPRT | Number of junctions for which output is printed. |

| Card | Column | Name | Description |
|---|---|---|---|
| | 26-35R. | DELT | Time interval, in seconds, used in solution. |
| | 36-45R. | TZERO | Time, in hours, at which computations begin. Allows starting point to be anywhere on tidal cycle. |
| | 46-50R | NETFLW | Option parameter. If NETFLW is specified as any non-zero integer Subroutine HYDEX is called to compute net flows and summarize hydraulic parameters. If NETFLW is specified as zero Subroutine HYDEX is not called. |
| 4 | 1-5R | IPRT | Printed output begins at this cycle number and at each NPRT cycles thereafter. |
| | 6-10R | IWRTE | Hydraulic parameters are stored on magnetic tape or disk beginning at this cycle number. |
| | 11-15R | KPNCHI | Punch interval for restarting. Magnetic tape is written at this cycle and at each KPNCHI cycles thereafter. |
| *5 | 1-5R | J | Junction number (read as dummy variable JJ to check card sequence). |
| | 6-15R. | Y(J) | Initial head specified at junction J, in feet. |
| | 16-25R. | AREAS(J) | Surface area of junction J, in square feet. |
| | 26-35R. | QIN(J) | Specified inflow or withdrawal at junction J, in cfs. Inflows must be assigned negative values, withdrawals positive. |
| | 36-40R | NCHAN(J,1) | Channel number of any one of the channels entering junction J. |

| Card | Column | Name | Description |
|---|---|---|---|
|  | 41-45R. | NCHAN(J,2) | Channel number of a second channel (if it exists) entering junction J If only a single channel element enters the junction NCHAN(J,2) and the remaining NCHAN values must be assigned a zero value. If exactly two channels enter the junction NCHAN(J,3) and the remaining NCHAN values must be assigned a zero value, etc. |
|  | .<br>.<br>.<br>. | .<br>.<br>.<br>. | .<br>.<br>.<br>. |
|  | 56-60R | NCHAN(J,5) | Channel number of the fifth channel (if it exists) entering junction J. If less than five channels enter the junction (NCHAN(J,5) must be assigned a zero value. |
|  | .... | .... | .... |
|  | .... | .... | Card 5 is repeated for each junction in the network (NJ cards). |
| *6 | 1-5R | N | Channel number (read as dummy variable NN to check card sequence). |
|  | 6-13R. | CLEN(N) | Length of channel N, in feet. |
|  | 14-21R. | B(N) | Width of channel N, in feet. |
|  | 22-29R. | AREA(N) | Initial cross-sectional area of channel N, in square feet. Must correspond to the initial heads specified at the junctions at the ends of the channel. |
|  | 30-37R. | R(N) | Hydraulic radius of channel N, in feet. Taken as the channel depth. |
|  | 38-45R. | CN(N) | Manning's roughness coefficient, dimensionless. |
|  | 46-53R. | V(N) | Initial mean velocity in channel N, in fps. |

| Card | Column | Name | Description |
|---|---|---|---|
|  | 54-58R | NJUNC(N,1) | The junction number at one end of channel N. |
|  | 59-63R | NJUNC(N,2) | The junction number at the other end of channel N. |
|  | .... | .... | Card 6 is repeated for each channel in the network (NC cards). |
| *7 | 1-5R | JPRT(1) | Numbers of those junctions for which printout is desired. There will be NOPRT different junction numbers, fourteen to a card. The numbers need not be in sequence. |
|  | 6-10R | JPRT(2) |  |
|  | 11-15R | JPRT(3) |  |
|  | . | . |  |
|  | . | . |  |
|  | . | . |  |
|  | . | . |  |
|  | .... | .... | Card 7 is repeated as many times as necessary to include all junction numbers for which printout is desired. |
| 8 | 1-5R | NK | Number of coefficients used to specify the tidal input |
| 9 | 1-10R. | PERIOD | Period of the input tide, in hours. |
|  | 11-20R. | A(1) | Coefficients for tidal input at specified junction(s). Obtained from regression analysis program, REGAN. |
|  | 21-30R. | A(2) |  |
|  | . | . |  |
|  | . | . |  |
|  | . | . |  |
|  | . | . |  |
|  | 71-80R. | A(7) |  |
| 10 | 1-80 | ALPHA(I) | Alphanumeric identifier--printed as part of heading for printout resulting from HYDEX. I = 41,60 with A4 format. |
| 11 | 1-80 | ALPHA(I) | Alphanumeric identifier--printed as part of heading for printout resulting from HYDEX. I = 61,80 with A4 format. |
| 12 | 1-5R | NODYN | Number of hydraulic time steps per quality time step. Defines the quality time step as the product of NODYN and DELT. |

NOTE: Cards 10, 11, and 12 are read by Subroutine HYDEX but immediately follow the previous data cards.

Variables Internal to Program DYNHYD

| Variable | Description |
|---|---|
| DELT2 | Half time step |
| W | $2\pi$ * PERIOD |
| G | Acceleration of gravity |
| KWRITE | Cycle number at which tape for restarting is written. KWRITE is updated throughout run. |
| T | Total elapsed time, in seconds. T is initially set equal to TZERO and is incremented by DELT at the start of each time step. |
| T2 | Total elapsed time, in seconds, for half-step computations. T2 always lags T by DELT2. |
| NS | Number of Sine (and Cosine) terms in relationship defining tidal input. |
| NL | Lowest number of the two junction numbers, NJUNC(N,1) or NJUNC(N,2) at the ends of a channel. |
| NH | Highest number of the two junction numbers, NJUNC(N,1) or NJUNC(N,2),at the ends of a channel. |
| KEEP | Temporary variable to store NJUNC(N,1) while NJUNC(N,1) and NJUNC(N,2) are interchanged. The two are interchanged whenever NJUNC(N,1) is a larger number than NJUNC(N,2). Following the interchange NJUNC(N,1) is always the smaller of the two numbers. |
| NCYCC | Counter for the number of hydraulic cycles (time steps) completed. |
| AKT | Friction coefficient during full-step computations. |

| Variable | Description |
|---|---|
| AKT2 | Friction coefficient during half-step computations. |
| YT(J) | Head at junction J during half-step. |
| AREAT(N) | Cross-sectional area of channel N during half-step. |
| VT(N) | Velocity in channel N during half-step. |
| Q(N) | Flow in channel N. |
| DVDX | Defines the velocity gradient $\Delta U/\Delta x$ in a channel. |
| SUMQ | The net inflow or outflow at a junction from all sources. |
| TIME | Total elapsed time, converted to hours. |
| VEL | Velocity, in feet per second, converted to sign convention used for hydraulic printout. |
| FLOW | Discharge, in cfs, converted to sign convention used for hydraulic printout. |
| TZERO2<br>KTZERO | Both are used temporarily to compute the appropriate value for TZERO in case of restarting. |
| Tape 3 | Tape 3 is the hydraulic extract tape created to serve as input to the quality program. Tape 3 also serves as a restart device in the event of premature termination of execution. |
| Tape 5 | Tape 5 indicates card input. |
| Tape 6 | Tape 6 indicates printed output. |
| Tape 8 | Tape 8 indicates punched output. |
| Tape 10 | Tape 10 used as a temporary (or permanent if desired) record of the entire hydraulic solution. Pertinent hydraulic parameters are stored on tape 10 for each time step and for every junction and channel in the system. |

## Variables Internal to Subroutine HYDEX

| Variable | Description |
|---|---|
| NSTOP | The last cycle completed in the hydraulic run. |
| NSTART | The last cycle number of the hydraulic run at which the last full tidal cycle began. The total number of cycles (time steps) in the full tidal cycle equals NSTOP - NSTART. |
| DELTQ | Time interval in hours, to be used in quality run and on which hydraulic parameters are to be summarized. DELTQ = (DELT * NODYN)/3600. |
| JRITE | The cycle number from the hydraulic run at which the hydraulic extract tape (Tape 3) is written. JRITE is initially set equal to NSTART and is then incremented by NODYN at the completion of each write command. |
| ICYCTF | Cycle number from the transient flow (hydraulic) program which was stored on tape 10. |
| YNEW(J) | A new name for the head at junction J to differentiate it from the head at the same junction at another time step. |
| QNET(N) | The mean or net flow in channel N over the full tidal cycle. QNET(N) is used to accumulate the entire flow in channel N over the full tidal cycle. This total is then divided by the number of hydraulic time steps comprising the tidal cycle to compute the net flow. |
| QEXT(N) | The mean flow in channel N over each quality time step. |
| VEXT(N) | The mean velocity in channel N over each quality time step. |
| VMIN(N) | The minimum velocity in channel N over the entire tidal cycle. If flow reversal occurs in channel N, VMIN(N) will be the maximum negative velocity. |
| VMAX(N) | The maximum velocity in channel N over the entire tidal cycle. If flow reversal occurs in channel N, VMAX(N) will be the maximum positive velocity. |

| Variable | Description |
|---|---|
| KFLAG | A flag which marks the beginning of the computations for determining the minimum and maximum cross-sectional areas in each channel. |
| KFLAG2 | A flag which marks the beginning of the computations for determining the minimum and maximum values of QEXT(N). |
| YAVE(J) | The mean head at junction J over the full tidal cycle. |
| YMIN(J) | The minimum head at junction J over the full tidal cycle. |
| NMIN(J) | The hydraulic cycle number at which the minimum head at junction J occurs. |
| YMAX(J) | The maximum head at junction J over the full tidal cycle. |
| NMAX(J) | The hydraulic cycle number at which the maximum head at junction J occurs. |
| ARAVE(N) | The mean cross-sectional area of channel N over the full tidal cycle. |
| ARMIN(N) | The minimum cross-sectional area of channel N over the full tidal cycle. |
| ARMAX(N) | The maximum cross-sectional area of channel N over the full tidal cycle. |
| QEXMIN(N) | The minimum of all the QEXT(N) values for channel N. |
| QEXMAX(N) | The maximum of all the QEXT(N) values for channel N. |
| RANGE (J) | The tidal range at junction J, i.e., RANGE(J) = YMAX(J) - YMIN(J). |

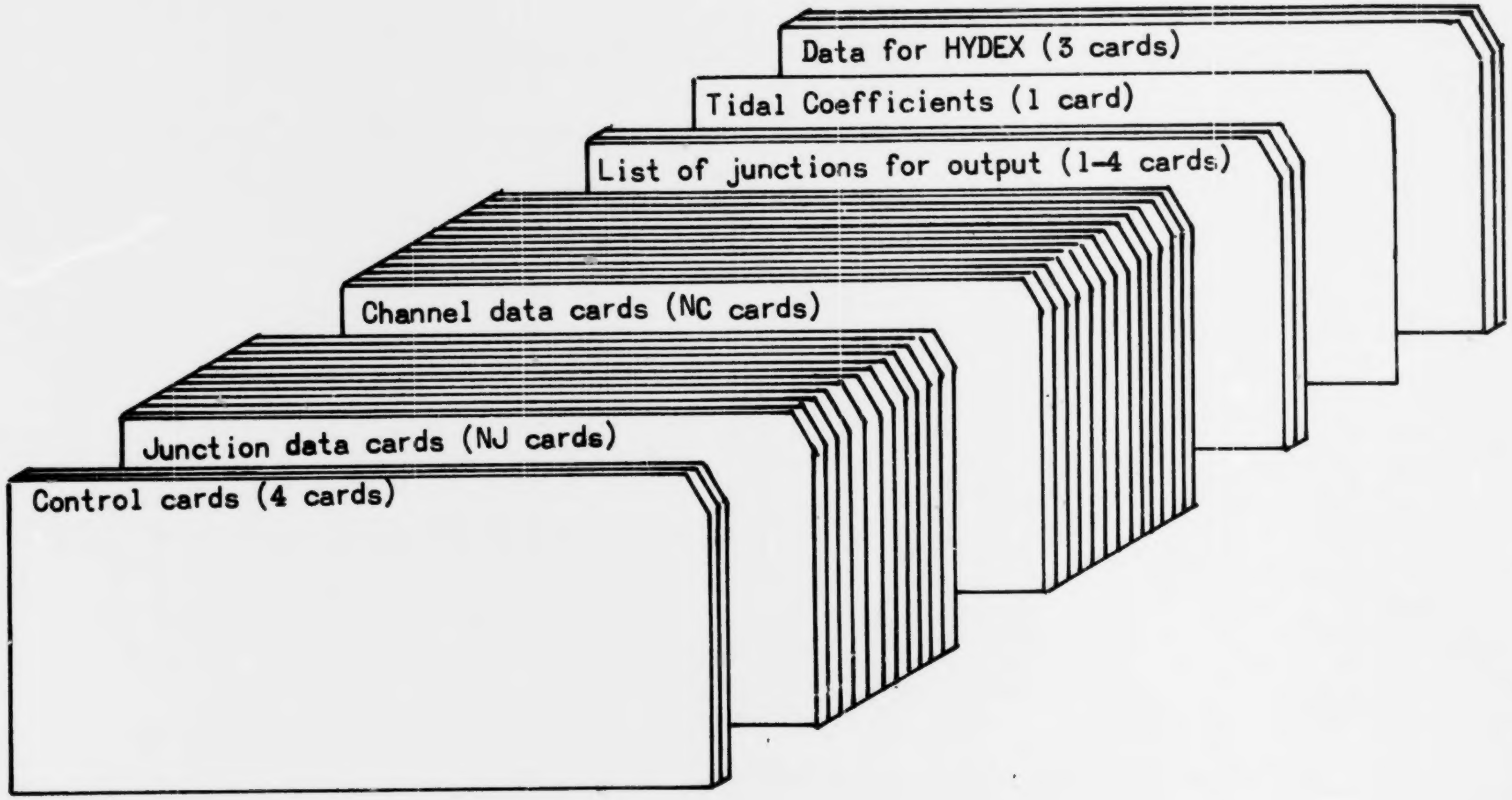

Data for HYDEX (3 cards)
Tidal Coefficients (1 card)
List of junctions for output (1-4 cards)
Channel data cards (NC cards)
Junction data cards (NJ cards)
Control cards (4 cards)

FIGURE 44. SAMPLE DATA DECK MAKEUP - PROGRAM DYNHYD

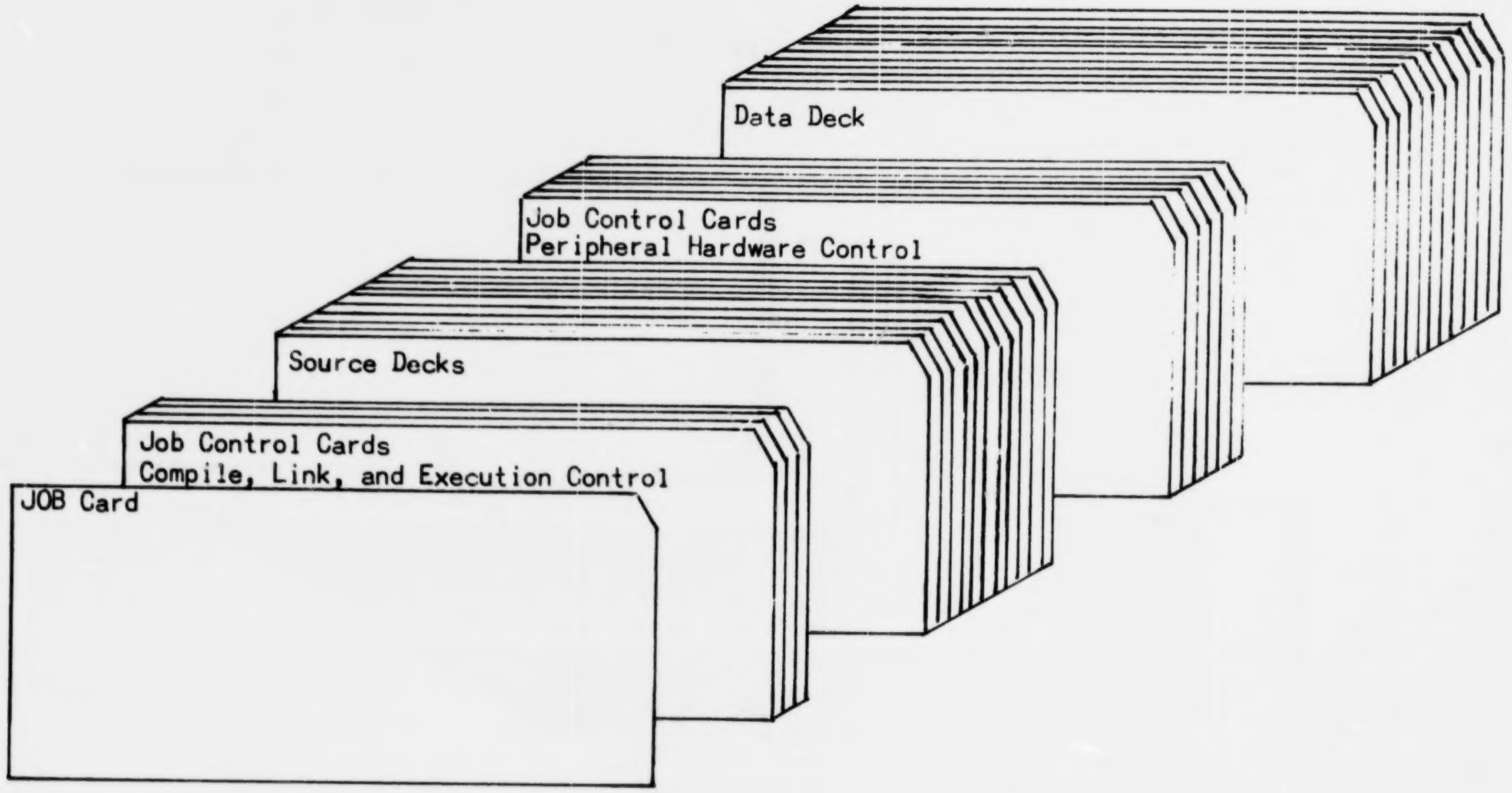

Data Deck
Job Control Cards
Peripheral Hardware Control
Source Decks
Job Control Cards
Compile, Link, and Execution Control
JOB Card

FIGURE 45. SAMPLE JOB DECK MAKEUP -- PROGRAM DYNHYD

## QUALITY PROGRAM (DYNQUA)

As with the hydraulic program the requirements for implementing the quality program can vary tremendously from run to run. Although certain provisions have been incorporated in the model to aid in implementing various types of quality studies the input data requirements may still be significant. These provisions and other features of the model will be discussed briefly in the following section. Following the discussion of the program logic a more thorough discussion of the input requirements, output options, special features, and potential implementation difficulties will be presented. Detailed descriptions and formats of the input variables and a description of program variables will also be included along with illustrations of the data deck and overall job deck. The program listing for the quality program is included in the Appendix along with a sample of the output from the program.

### Flow Diagram and Program Logic

The quality program has been changed significantly since the development by the contractor. In addition to the previously discussed changes in the method utilized for advective transport several routines have been incorporated to handle special quality problems (such as agricultural water use), to decrease computation time to attain steady state conditions, or to provide more flexibility in the types and quantities of output obtained. In general it is possible to bypass these special routines with specification of appropriate control parameters. It might also be appropriate, in certain cases, to remove them from the program entirely; however, it is suggested that this latter alternative not be exercised until a user is intimately familiar with the program as the effect on other portions of the program may not always be apparent.

The discussion of the program logic will generally follow the simplified flow diagram presented in Figure 46. The numbers adjacent to each step are for reference only and do not refer to numbers within the program.

The network size (number of junctions and channels), the starting and stopping point on the hydraulic extract tape, and the quality time step are specified as the initial step of the quality program. The hydraulic extract tape (tape 3) is then read completely through to obtain the geometric and physical data for the system (step 2). The tape is then rewound to ready it for reading the hydraulic parameters for each time step stored at the beginning of the tape. The starting point on the tape is specified along with the length of the run, the output options, and other control parameters (step 3). These parameters are printed as part of the heading to identify the run (step 4).

The number of quality constituents to be considered, their characteristics (conservative, non-conservative, decay coefficients, etc.), and an alphanumeric identifier for each constituent are specified (step 5). The upper concentration limit for each constituent (above

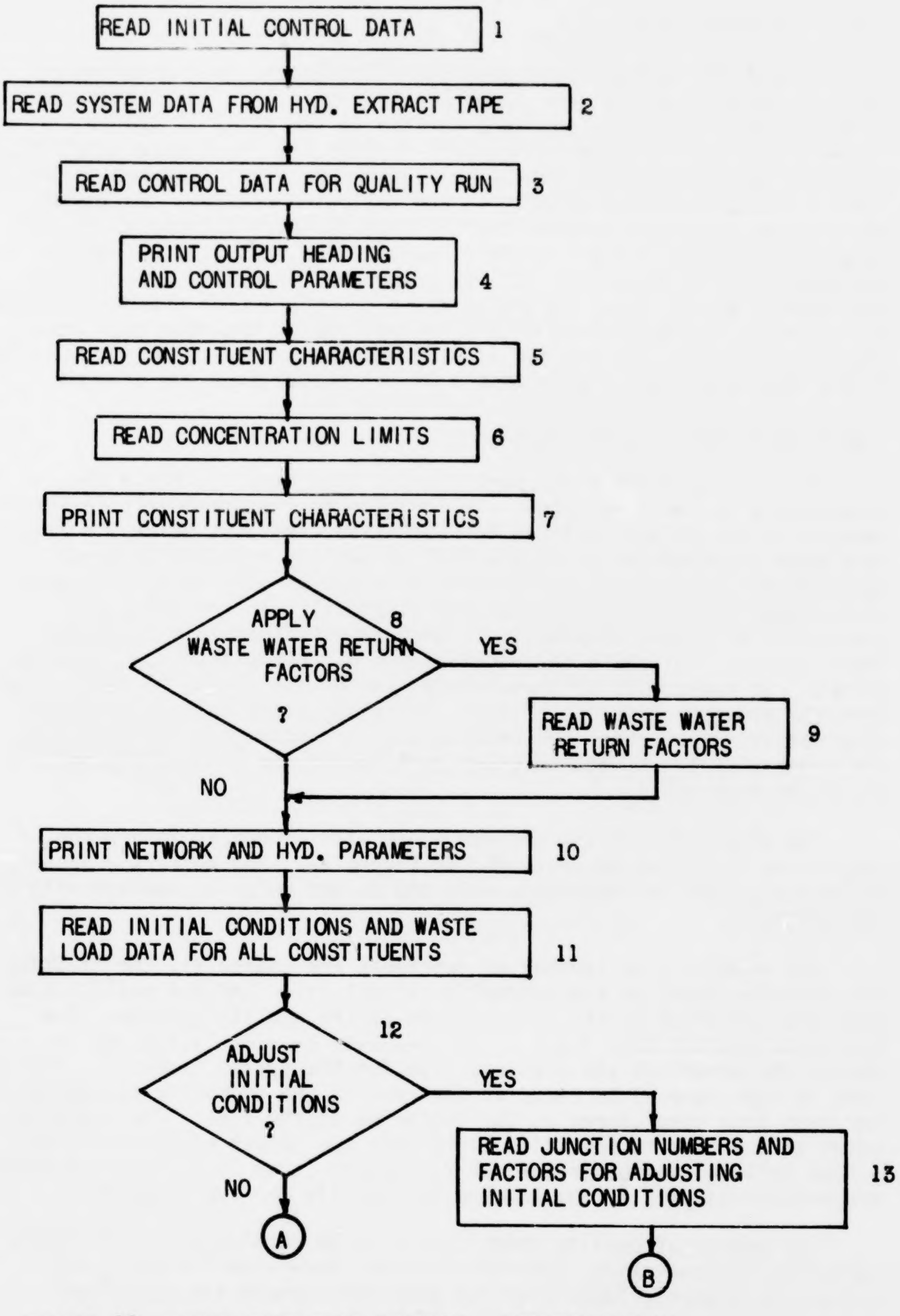

READ INITIAL CONTROL DATA
1
READ SYSTEM DATA FROM HYD. EXTRACT TAPE
2
READ CONTROL DATA FOR QUALITY RUN
3
PRINT OUTPUT HEADING AND CONTROL PARAMETERS
4
READ CONSTITUENT CHARACTERISTICS
5
READ CONCENTRATION LIMITS
6
PRINT CONSTITUENT CHARACTERISTICS
7
APPLY WASTE WATER RETURN FACTORS ?
8
YES
READ WASTE WATER RETURN FACTORS
9
NO
PRINT NETWORK AND HYD. PARAMETERS
10
READ INITIAL CONDITIONS AND WASTE LOAD DATA FOR ALL CONSTITUENTS
11
ADJUST INITIAL CONDITIONS ?
12
YES
READ JUNCTION NUMBERS AND FACTORS FOR ADJUSTING INITIAL CONDITIONS
13
NO
A
B

FIGURE 46. SIMPLIFIED FLOW DIAGRAM - PROGRAM DYNQUA

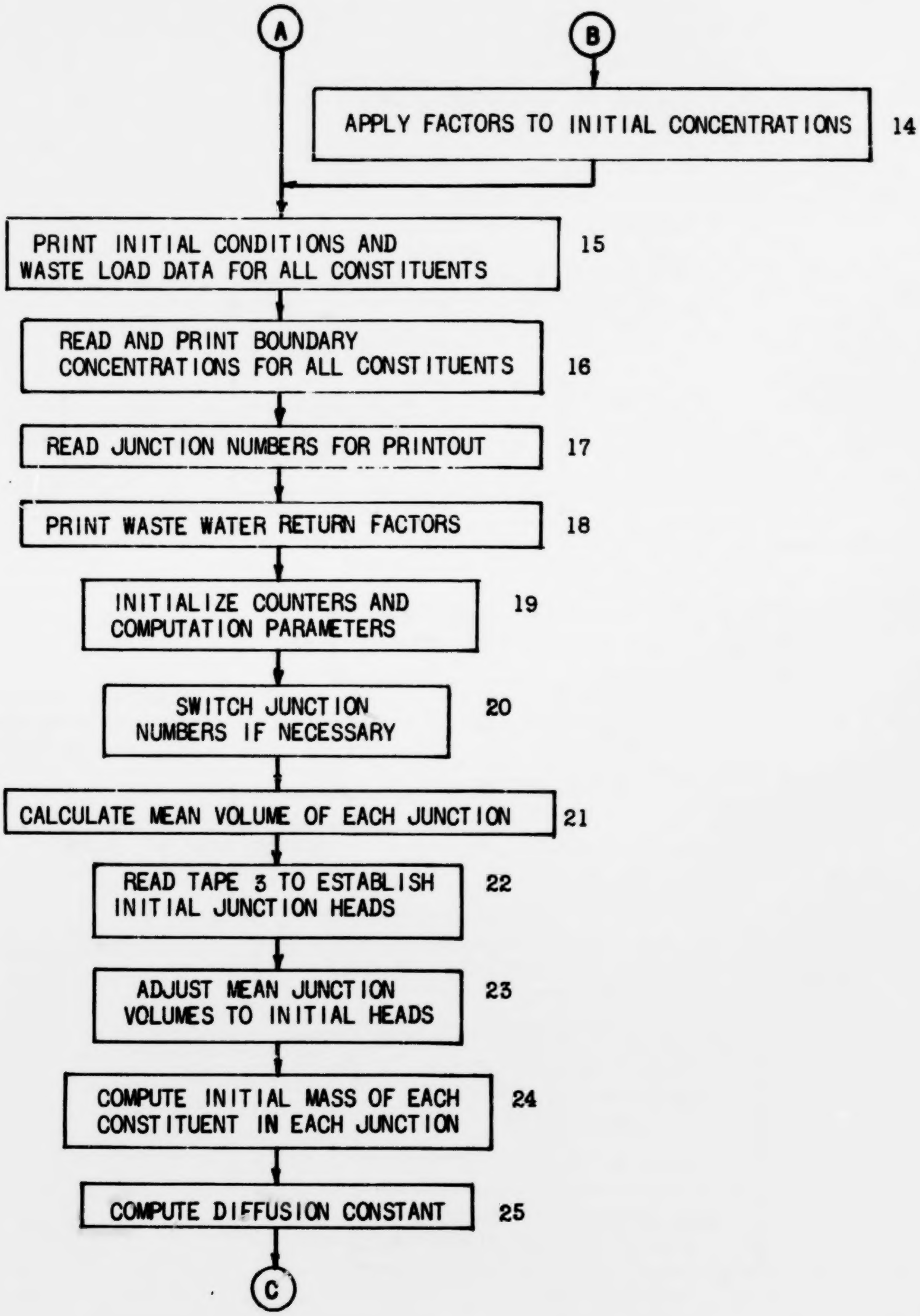

A
B
APPLY FACTORS TO INITIAL CONCENTRATIONS
14
PRINT INITIAL CONDITIONS AND WASTE LOAD DATA FOR ALL CONSTITUENTS
15
READ AND PRINT BOUNDARY CONCENTRATIONS FOR ALL CONSTITUENTS
16
READ JUNCTION NUMBERS FOR PRINTOUT
17
PRINT WASTE WATER RETURN FACTORS
18
INITIALIZE COUNTERS AND COMPUTATION PARAMETERS
19
SWITCH JUNCTION NUMBERS IF NECESSARY
20
CALCULATE MEAN VOLUME OF EACH JUNCTION
21
READ TAPE 3 TO ESTABLISH INITIAL JUNCTION HEADS
22
ADJUST MEAN JUNCTION VOLUMES TO INITIAL HEADS
23
COMPUTE INITIAL MASS OF EACH CONSTITUENT IN EACH JUNCTION
24
COMPUTE DIFFUSION CONSTANT
25
C

FIGURE 46.(Cont.)

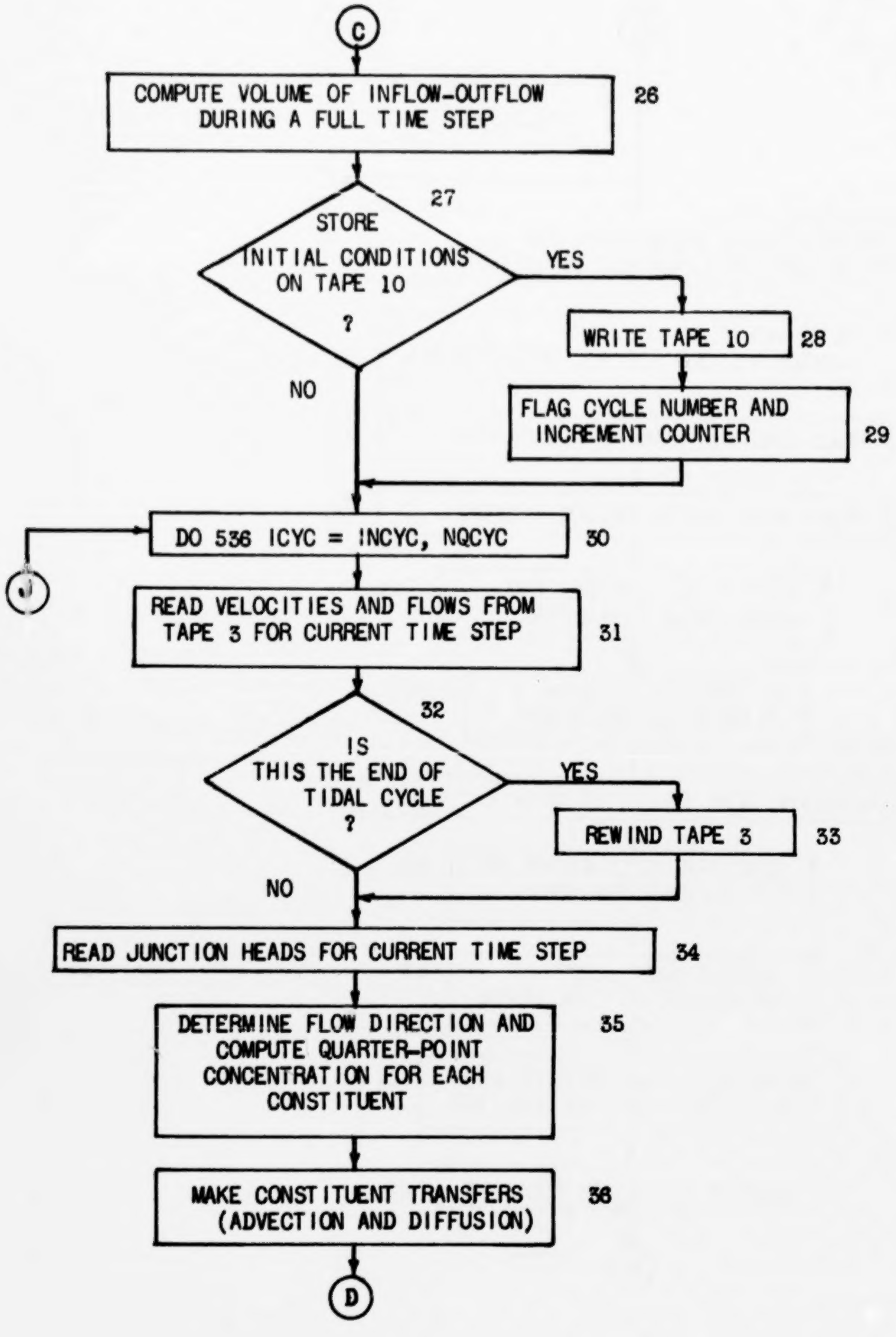

C
COMPUTE VOLUME OF INFLOW-OUTFLOW DURING A FULL TIME STEP
26
27
STORE INITIAL CONDITIONS ON TAPE 10 ?
YES
WRITE TAPE 10
28
NO
FLAG CYCLE NUMBER AND INCREMENT COUNTER
29
DO 536 ICYC = INCYC, NQCYC
30
J
READ VELOCITIES AND FLOWS FROM TAPE 3 FOR CURRENT TIME STEP
31
32
IS THIS THE END OF TIDAL CYCLE ?
YES
REWIND TAPE 3
33
NO
READ JUNCTION HEADS FOR CURRENT TIME STEP
34
DETERMINE FLOW DIRECTION AND COMPUTE QUARTER-POINT CONCENTRATION FOR EACH CONSTITUENT
35
MAKE CONSTITUENT TRANSFERS (ADVECTION AND DIFFUSION)
36
D

FIGURE 46 (Cont.)

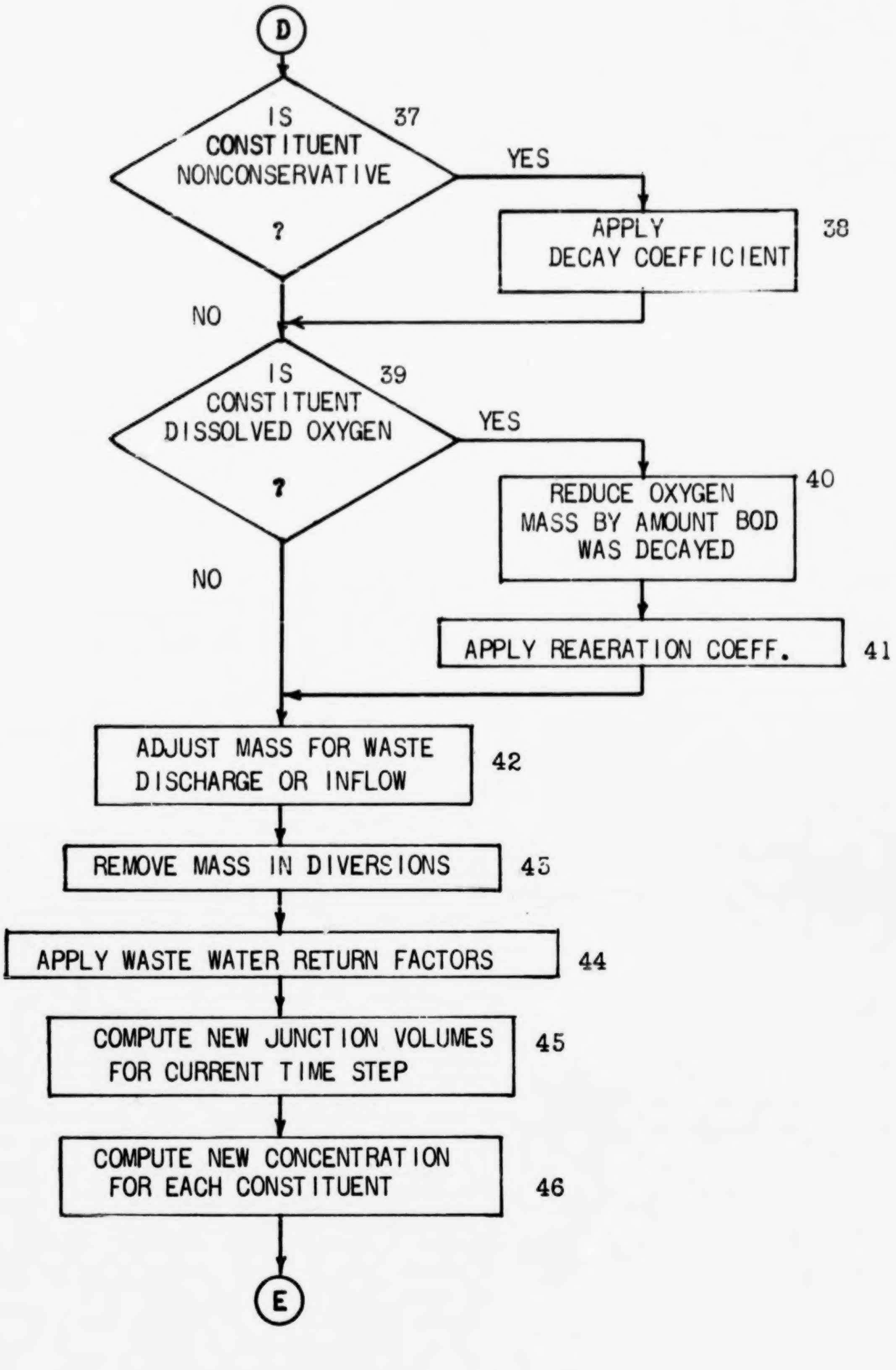

D
IS CONSTITUENT NONCONSERVATIVE ?
37
YES
APPLY DECAY COEFFICIENT
38
NO
IS CONSTITUENT DISSOLVED OXYGEN ?
39
YES
REDUCE OXYGEN MASS BY AMOUNT BOD WAS DECAYED
40
NO
APPLY REAERATION COEFF.
41
ADJUST MASS FOR WASTE DISCHARGE OR INFLOW
42
REMOVE MASS IN DIVERSIONS
43
APPLY WASTE WATER RETURN FACTORS
44
COMPUTE NEW JUNCTION VOLUMES FOR CURRENT TIME STEP
45
COMPUTE NEW CONCENTRATION FOR EACH CONSTITUENT
46
E

FIGURE 46 (Cont.)

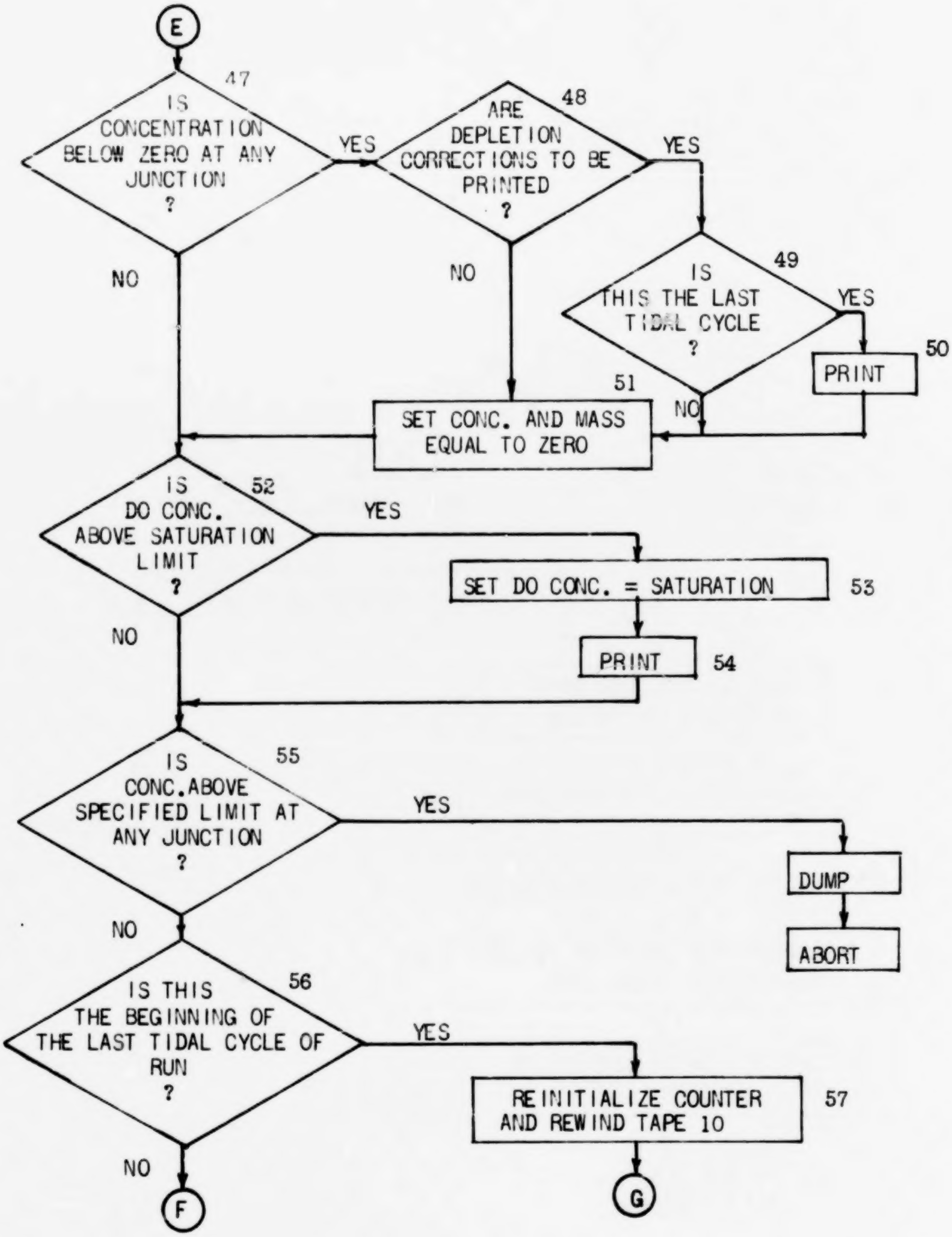

E
47
IS CONCENTRATION BELOW ZERO AT ANY JUNCTION ?
YES
48
ARE DEPLETION CORRECTIONS TO BE PRINTED ?
YES
NO
NO
49
IS THIS THE LAST TIDAL CYCLE ?
YES
50
PRINT
51
SET CONC. AND MASS EQUAL TO ZERO
NO
52
IS DO CONC. ABOVE SATURATION LIMIT ?
YES
SET DO CONC. = SATURATION
53
NO
PRINT
54
55
IS CONC. ABOVE SPECIFIED LIMIT AT ANY JUNCTION ?
YES
DUMP
ABORT
NO
56
IS THIS THE BEGINNING OF THE LAST TIDAL CYCLE OF RUN ?
YES
REINITIALIZE COUNTER AND REWIND TAPE 10
57
NO
F
G

FIGURE **46** (Cont.)

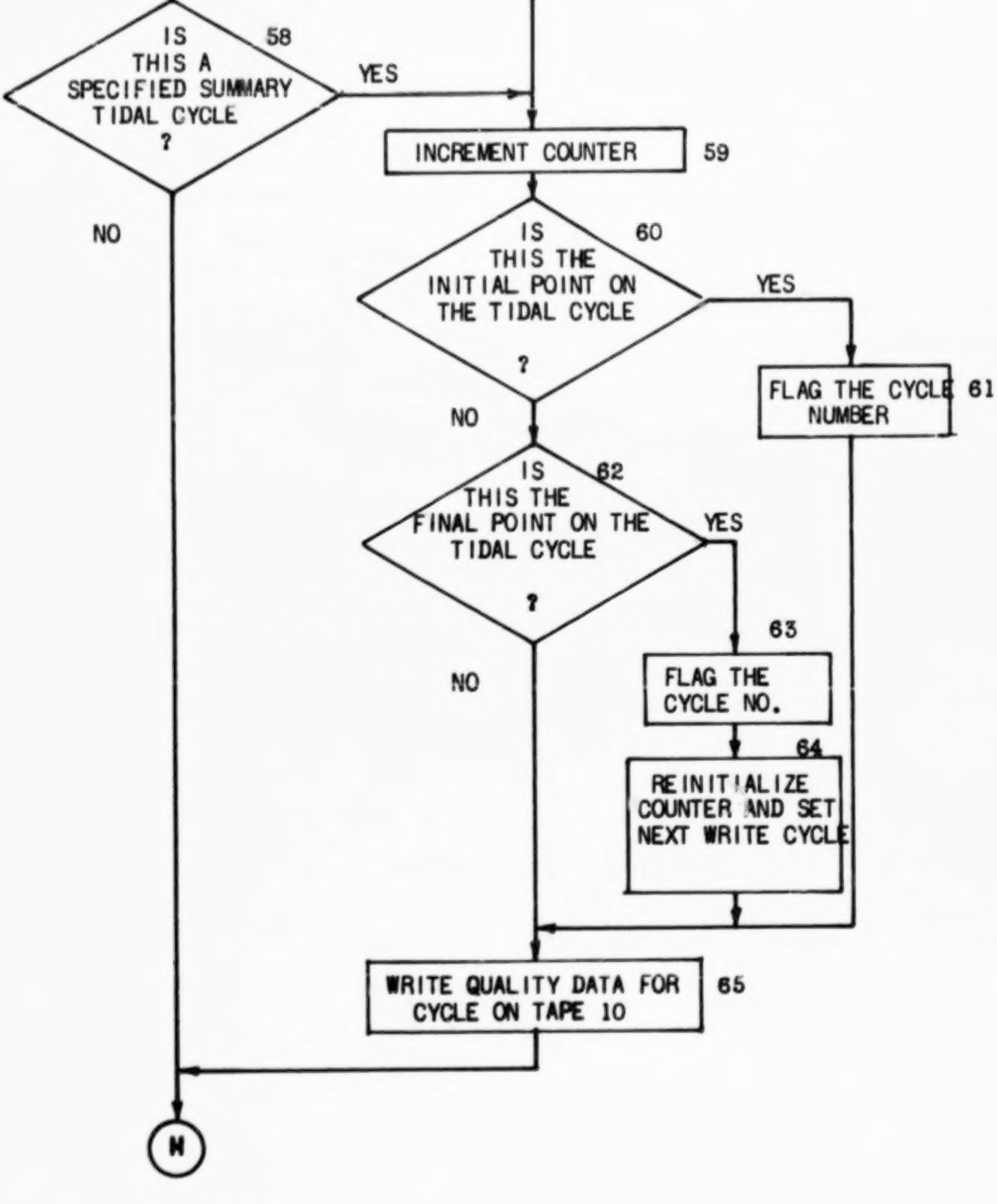

F
G
IS THIS A SPECIFIED SUMMARY TIDAL CYCLE ?
58
YES
NO
INCREMENT COUNTER
59
IS THIS THE INITIAL POINT ON THE TIDAL CYCLE ?
60
YES
NO
FLAG THE CYCLE NUMBER
61
IS THIS THE FINAL POINT ON THE TIDAL CYCLE ?
62
YES
NO
63
FLAG THE CYCLE NO.
64
REINITIALIZE COUNTER AND SET NEXT WRITE CYCLE
WRITE QUALITY DATA FOR CYCLE ON TAPE 10
65
H

FIGURE 46 (Cont.)

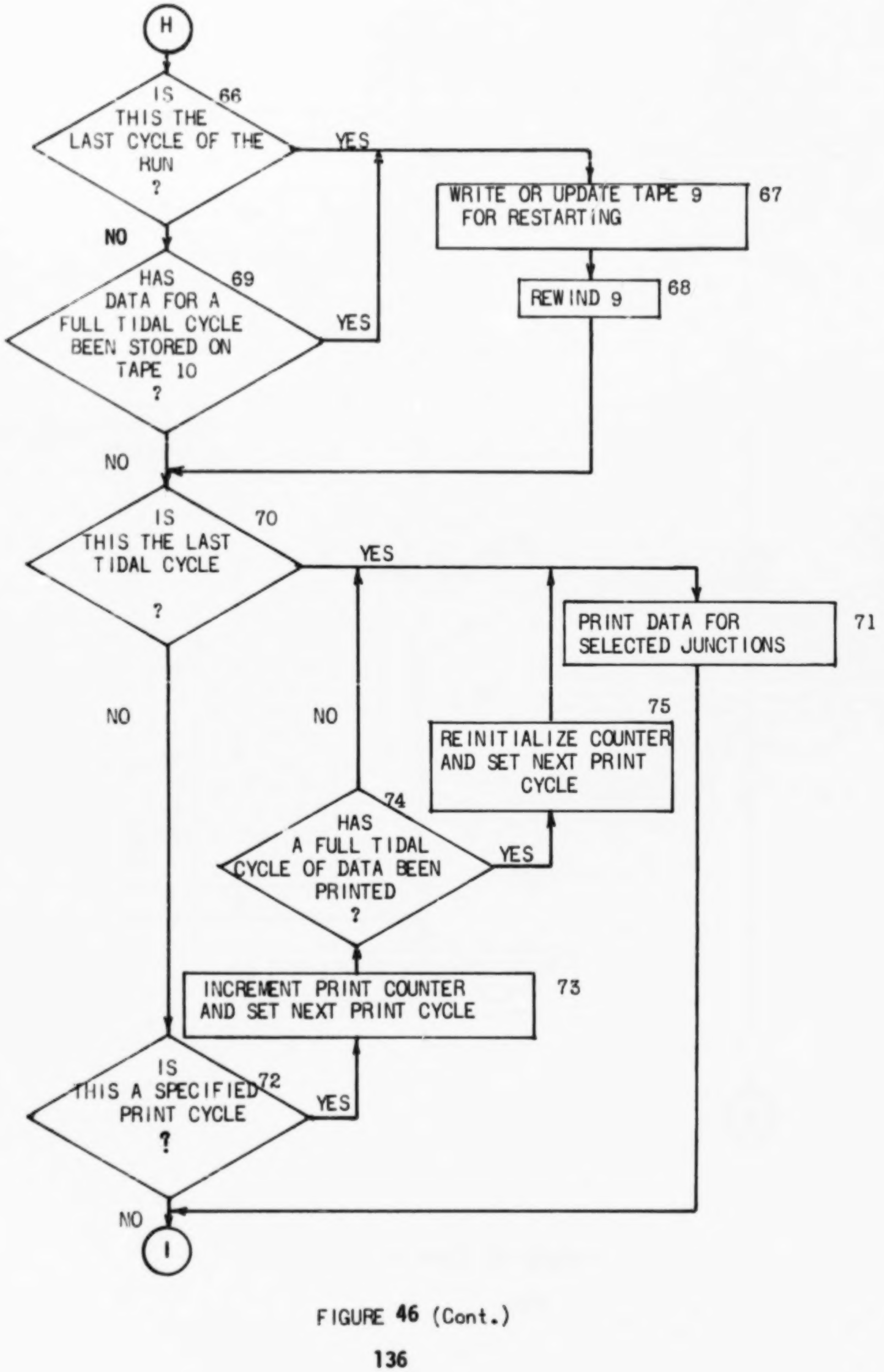
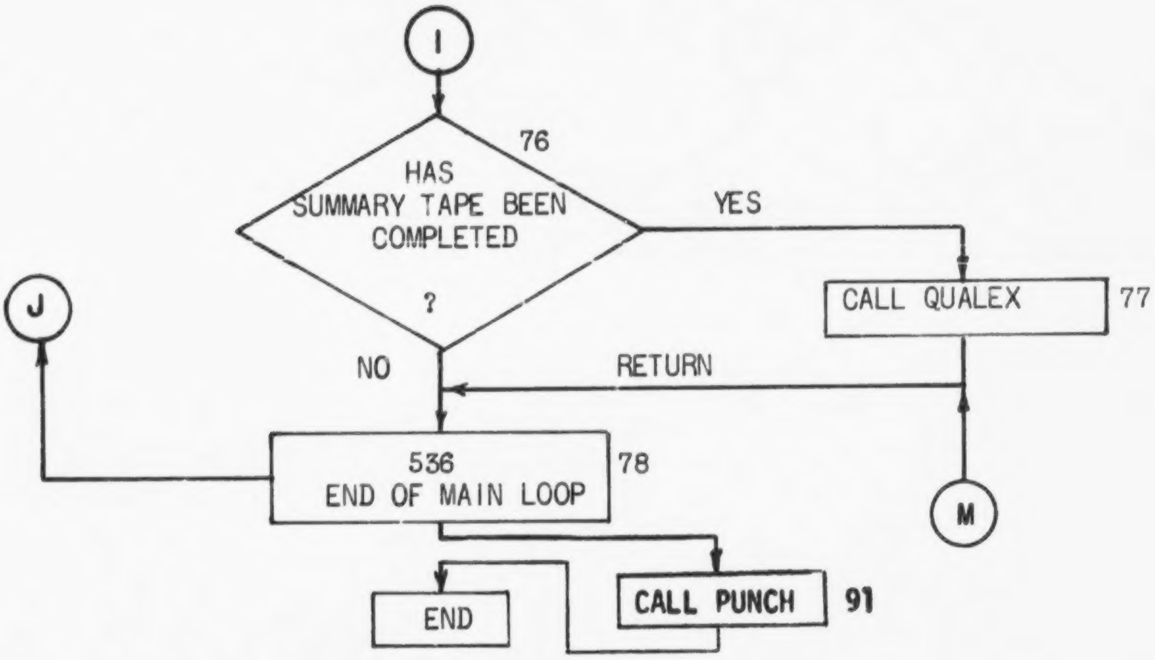

H
IS THIS THE LAST CYCLE OF THE RUN ?
66
YES
NO
WRITE OR UPDATE TAPE 9 FOR RESTARTING
67
REWIND 9
68
HAS DATA FOR A FULL TIDAL CYCLE BEEN STORED ON TAPE 10 ?
69
YES
NO
IS THIS THE LAST TIDAL CYCLE ?
70
YES
NO
PRINT DATA FOR SELECTED JUNCTIONS
71
NO
REINITIALIZE COUNTER AND SET NEXT PRINT CYCLE
75
HAS A FULL TIDAL CYCLE OF DATA BEEN PRINTED ?
74
YES
INCREMENT PRINT COUNTER AND SET NEXT PRINT CYCLE
73
IS THIS A SPECIFIED PRINT CYCLE ?
72
YES
NO
I

FIGURE 46 (Cont.)



SUBROUTINE QUALEX

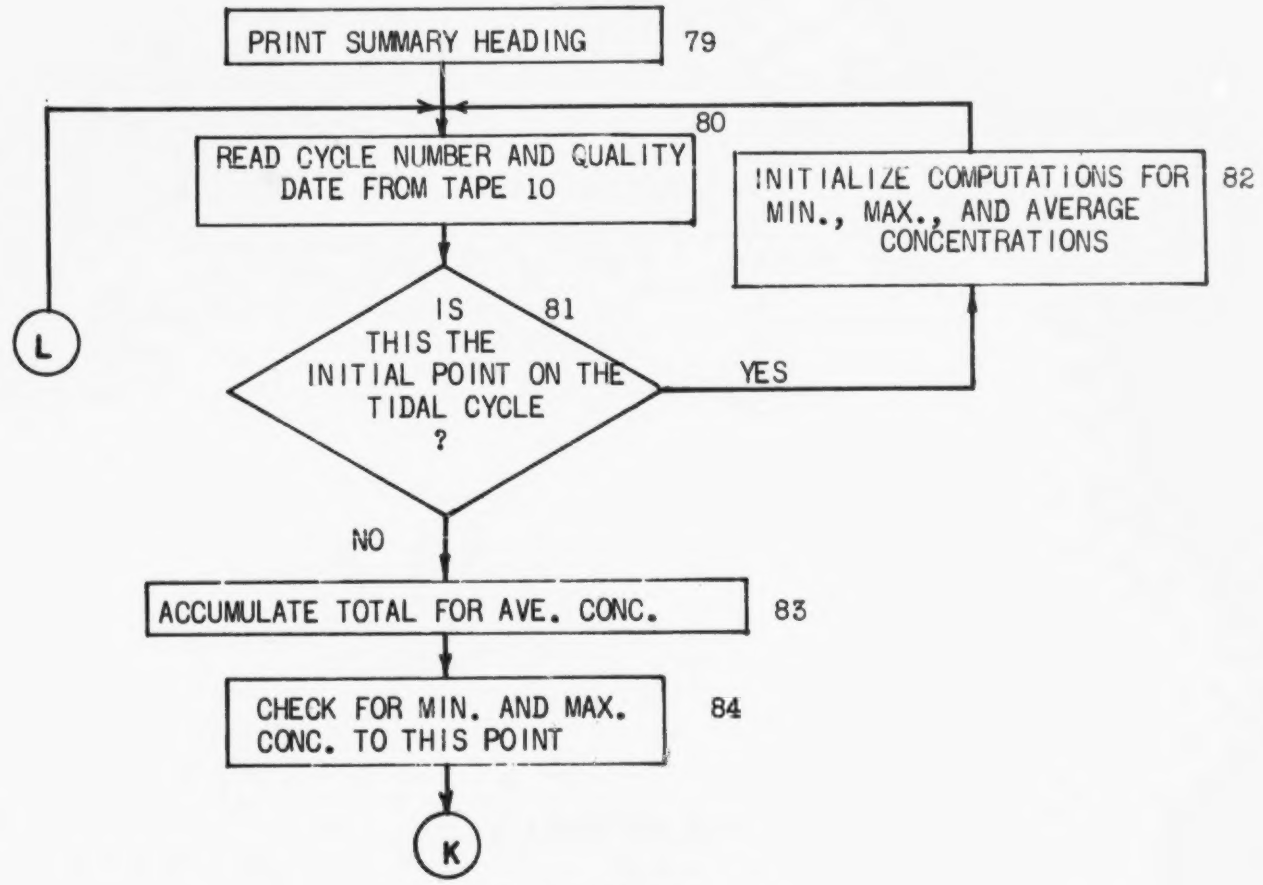

PRINT SUMMARY HEADING
79
80
READ CYCLE NUMBER AND QUALITY DATE FROM TAPE 10
INITIALIZE COMPUTATIONS FOR MIN., MAX., AND AVERAGE CONCENTRATIONS
82
L
IS THIS THE INITIAL POINT ON THE TIDAL CYCLE ?
81
YES
NO
ACCUMULATE TOTAL FOR AVE. CONC.
83
CHECK FOR MIN. AND MAX. CONC. TO THIS POINT
84
K

FIGURE 46 (Cont.)

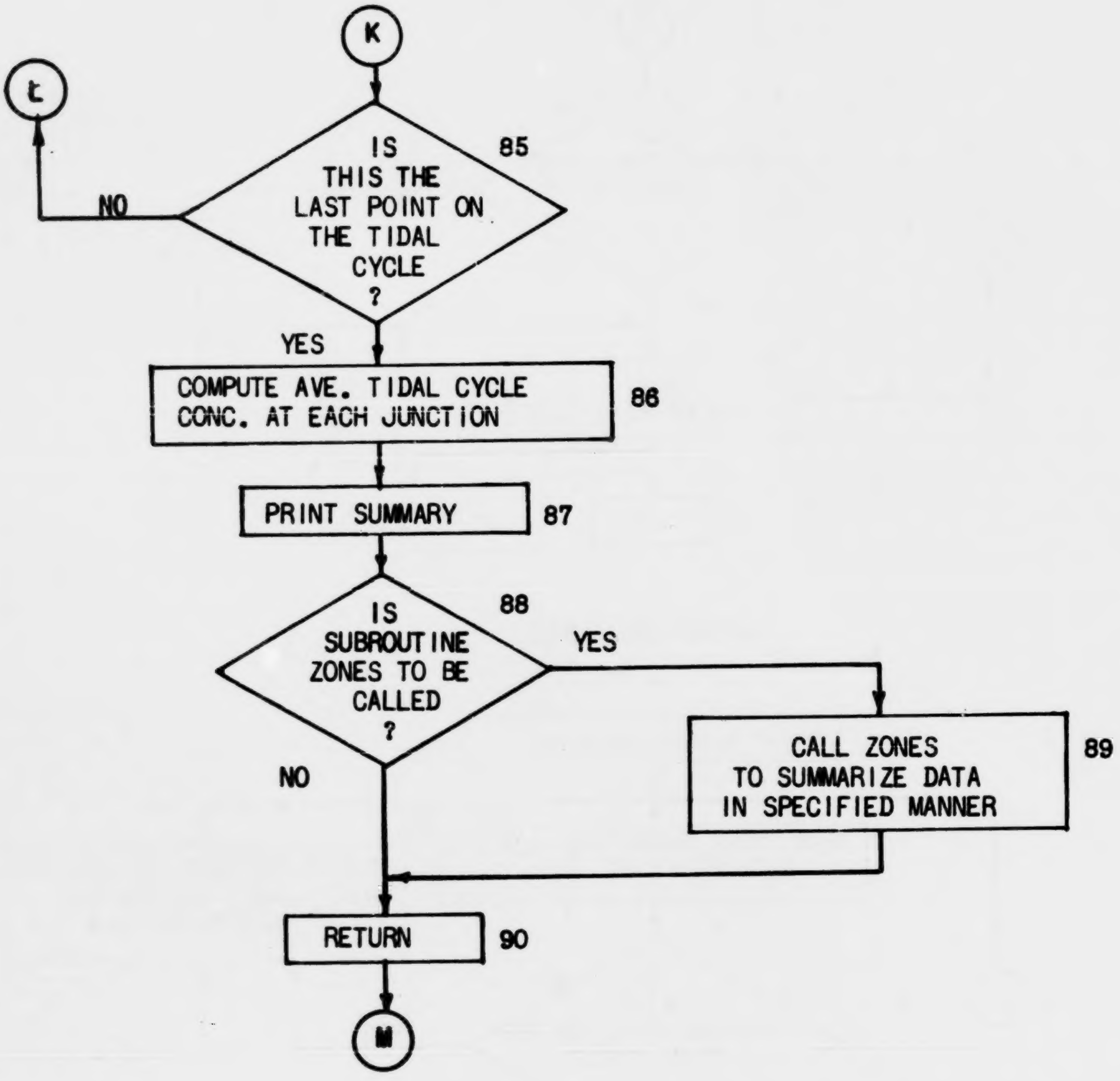

K
t
IS THIS THE LAST POINT ON THE TIDAL CYCLE ?
85
NO
YES
COMPUTE AVE. TIDAL CYCLE CONC. AT EACH JUNCTION
86
PRINT SUMMARY
87
IS SUBROUTINE ZONES TO BE CALLED ?
88
YES
NO
CALL ZONES TO SUMMARIZE DATA IN SPECIFIED MANNER
89
RETURN
90
M

FIGURE 46 (Cont.)

which execution is terminated) is specified (step 6) and the constituent characteristics are printed to identify the run (step 7).

If waste water return factors are to be applied (step 8) the specified diversion and return flow junctions and the factors to be applied are read (step 9). A summary of the network and hydraulic parameters is printed to provide a reference for the inputs which had been specified for the hydraulic run on which the quality run is based (step 10).

The quality waste loads (flows and concentrations for each constituent) are read along with the initial concentrations of each constituent at each junction (step 11). If the initial concentrations for any constituent are to be adjusted (step 12) the multiplication factors are read (step 13) and applied to specified groups of junctions (step 14). The adjusted concentrations and a summary of the specified waste loads are printed for reference (step 15).

The seaward boundary concentrations for each constituent for each time step over a tidal cycle are read and printed (step 16). If the concentration of a particular constituent does not vary over the tidal cycle a constant value can be specified. The list of junction numbers for which quality predictions within a tidal cycle are to be printed is read (step 17). The waste water return factors which had been read previously are printed at this point (step 18) and the various counters, flags, and computation parameters are initialized (step 19). The junction numbers assigned to each channel are interchanged, if necessary, to assure compatibility with the sign convention established in the hydraulic run (step 20).

The mean volume of each junction is computed, based on the mean depth computed in the hydraulic run (step 21). Tape 3 is then positioned at the hydraulic cycle number at which the quality run is to begin and the junction heads are read (step 22). The mean junction volumes are then adjusted to the new heads (step 23) to establish the volume of the system at the start of the quality run.

The total initial mass of each constituent is computed for each junction (step 24) and the diffusion constant is computed for each channel (step 25). The total volume of inflow (or withdrawal) at each junction during a quality time step is computed (step 26) prior to entering the main computation loop.

A check is made to determine if the initial conditions are to be written on tape 10 (step 27) for summarizing the predictions over the first tidal cycle. If so the values are stored on tape 10 (step 28), the cycle number is flagged and a counter is incremented which records the number of times the tape is written (step 29).

Step 30 begins the main computation loop which is executed for each time step. Tape 3, which had been properly positioned prior to entering the main loop is read to establish the initial channel velocities and flows in each channel (step 31). A check is made (step 32) each time the tape is read to determine if the end of the tidal cycle has been reached. If so, the tidal cycle will be repeated by rewinding tape 3 (step 33) and reading the junction heads for the start of the next time step (step 34). If the end of the tidal cycle has not been reached the heads for the next time step are read as the next record on the tape.

Transfers of quality constituents are made from junction to junction based on the flow in the connecting channel and on the concentration gradient between the junctions. The flow direction in each channel is determined and the concentration at the quarter point (from the upstream end) of the channel is computed (step 35). The mass of constituent to be transferred in each channel both by advection and diffusion, is then computed and the transfers made (step 36).

For each non-conservative constituent the mass existing at each junction is decayed by applying the specified decay coefficient (steps 37 and 38). If a constituent is dissolved oxygen (step 39) its mass at each junction is reduced by the amount the associated BOD was decayed (step 40) and the specified oxygen reaeration coefficient applied to the saturation deficit existing (step 41).

At each junction where an inflow or a waste discharge exists constituent is added to the system (at the concentration specified for the input) and at junctions where diversions exist constituent is removed at the concentration existing at the junction (steps 42 and 43). The waste water return factors are then applied to the specified junctions (step 44).

The new concentrations at each junction are then computed by first adjusting the junction volumes to the start of the next time step (step 45) and then dividing the mass of each constituent by the new volume (step 46).

If the predicted concentration at any junction is below zero (step 47) the concentration and the mass are set equivalent to zero (step 51). A statement pointing out the correction is either printed (step 50) or not depending on the control option specified (step 48) and on whether computations have proceeded to the last tidal cycle of the run (step 49). Guidelines for printing or suppressing these print statements are included in a later section.

To prevent supersaturation of dissolved oxygen the predicted concentration is set equivalent to the specified saturation concentration if the saturation concentration is exceeded (steps 52 and 53) and a statement to that effect is printed (step 54).

The predicted concentrations are also checked against the specified upper limits for each constituent and the run is aborted if any limit is exceeded (step 55).

A summary (minimum, maximum, and average concentrations over the full tidal cycle) of the predictions for the last full tidal cycle is always provided. Therefore at the start of the last tidal cycle (step 56) tape 10 is rewound and the counter for writing the tape is reinitialized to zero (step 57). The counter is then incremented to unity (step 59), the cycle number (time step) flagged (step 61), and the predictions stored on tape 10 (step 65). For all time steps other than that marking the start of the last tidal cycle a check is made to determine whether the predictions for the time step are to be included in a summary or not (step 58). If so, the counter recording the number of times tape 10 is written is incremented (step 59) and a check made (step 60) to determine whether the counter has a value equal to unity (indicating the start of the record on tape 10) or greater than unity (indicating the continuation of the record on the tape). For the initial record the time step number is flagged (step 61) and the tape is written (step 65). For time steps beyond that of the initial record a check is made to determine whether the end point of the full tidal cycle of data has been reached (step 62). The number of the time step marking the end of the record on tape 10 is also flagged (step 63), the counter is reinitialized to zero and the time step number marking the start of the next summary is set (step 64) before the tape is written (step 65).

When the last computation cycle of the run is reached (step 66) the final predictions are stored on tape 9 (step 67). The record on tape 9 can be used to extend the run at a later time, if necessary. Restart capability is also provided each time the summary is obtained (step 69). Tape 9 is rewound (step 68) at the completion of each update so that only the most recent predictions are retained.

Printout is automatically obtained for each time step of the last full cycle of the run (steps 70 and 71). For other print cycles (step 72) the print counter is incremented and the next print cycle set (step 73). Printout continues at the specified print interval until a full tidal cycle of printout is obtained (as determined at step 74) at which point the print counter is reinitialized and the next print cycle (usually several tidal cycles later) established (step 75).

At the completion of storing a full tidal cycle of data on tape 10 (step 76) subroutine QUALEX is called (step 77) to summarize the data. Following the summary, control returns to the end of the main computation loop (step 78) and execution proceeds for the specified number of cycles.

A heading to identify the summary is provided each time subroutine QUALEX is called (step 79). A cycle number (and its associated data) is read from tape 10 (step 80) and, for the initial time step on the tape (as determined at step 81) the computations for the minimum, maximum, and average concentrations for each constituent are initialized (step 82). The data for the next time step is then read from tape 10 (step 80) and the new concentrations for each constituent are added to the accumulated totals for determining the average (step 83).

The previously established values for the minimum and maximum concentrations are checked against the new concentrations at each junction and are updated if necessary (step 84). Following the last cycle on tape 10 (as determined at step 85) the average concentration over the full tidal cycle is computed (step 86). The results of the summary are printed (step 87) and depending on the specified control option (step 88) subroutine ZONES is either called (step 89) or not (step 90) before returning to the main program (step 90). Prior to program termination subroutine PUNCH is called (step 91) to punch the restart record stored previously on tape 9. A discussion of subroutine ZONES is included in a later section.

## Input Data Requirements

As the quality model has been refined and developed by FWQA the input data requirements to execute the program have increased. Generally, the additional inputs are required to provide additional flexibility in the types of problems that can be modeled or studied, to better control the types and quantities of output obtained, or to reduce the required execution time to attain steady state predictions.

For discussion purposes the inputs will be broken into four categories: control parameters, waste load data, initial conditions, and boundary conditions.

Control parameters. The control parameters are required to specify the number and types of quality constituents, the length of the run, the type and frequency of printout, the time step to be utilized, the starting point on the tidal cycle, etc. The specification of these parameters is generally straightforward and does not present a problem. A more complete description of these parameters (variable names, format, etc.) is included in a later section.

Waste Load Data. Although not always the most difficult to specify, the waste loads to the system are the most basic inputs to any quality simulation. These inputs include the specification of the concentration of each constituent considered in each hydraulic inflow to the system, e.g., streamflows, storm runoff, waste water discharges from any source, etc. It is through these inputs that the appropriate mass of each constituent is added to the system during the time period considered. For inflows and wastewater discharges it is necessary to specify both the hydraulic and quality inputs, i.e., flow and concentration, in order to define the rate of addition of quality constituent. For diversions it is necessary to specify only the flow since the constituent is removed at the concentration existing (computed) at the diversion point. For convenience the hydraulic component at each junction will normally be the same as specified in the hydraulic run (except as noted below). The hydraulic behavior of the system for each quality time step has been fixed in the hydraulic program and is not affected by the inflows or waste discharges specified in the quality program. Thus if a diversion existed in the hydraulic solution it is necessary to re-specify that diversion in the quality solution in order that the appropriate mass of constituent be removed, otherwise water will be removed but not constituent. Similarly if an inflow or waste discharge existed in the hydraulic solution it is necessary to specify both the flow rate and the concentration in order to add the appropriate mass of constituent during each time step. If either component is not specified water will be added but not constituent. As was discussed previously in Part I, this feature of the quality model allows the effects of evaporation and precipitation to be included in the quality predictions.

This feature makes it convenient to add constituent at any desired point in the system regardless of whether a hydraulic inflow exists at the point. For simulating a release of dye or other tracer constituent wherein a very small quantity of tracer (but with high concentration) is released any convenient flow rate and concentration can be specified such that the appropriate mass is added each time step. Because of the programmed output formats it may be necessary to scale the inputs such that the desired units are obtained e.g. parts per million or parts per billion.

For certain water uses the concentration of the waste water return is dependent on the quality of the water diverted or on other factors such as described previously in Part I for agricultural water use. The model can treat such diversions and waste water returns in a special way. If water is diverted from the system for a specific use and all or part of the diversion is subsequently returned at the same or a different concentration it is possible to relate the total mass of constituent returned to that diverted as indicated previously by equation 44.

$$Q_dC_d = mQ_aC_a + b \qquad (44)$$

The junction from which the water is diverted is paired with the junction at which the waste water is returned. For convenience such pairs of diversions and waste water returns are grouped into units, two pairs to a unit. The same return factor m and constant b are applied to both pairs within a unit. In certain cases, wherein it is desired to relate a single return to a single diversion, a unit will have only a single pair; however, the program logic requires that appropriate dummy junction numbers be included to fill out the unit. This can easily be accomplished by selecting any two junctions which have no assigned inflows or withdrawals as the dummy junctions to be included. The entire routine for applying the waste water return factors can be bypassed by specifying the number of units (NUNITS) as zero.

One additional input required for each constituent which is to be treated as non-conservative is the decay rate (or reaeration rate) constant to be applied. The desired rate is expressed for a time base of one day (e.g. 0.23 per day, base e). Because the model uses a smaller time step (such as one-half hour) the rate is converted to the appropriate time base by an expression of the form:

$$D = e^{-K\Delta t}$$

where $\Delta t$ is equal to the quality time step used (in days), K is the decay (or reaeration) rate per day, e is the base of the natural logarithms, and D is the decay factor or reaeration rate applied to the mass at each junction during each time step. The conversion is internal to the program; therefore the required input must be for a time base of one day and for logarithm base e.

Initial Conditions. For certain studies (for example prediction of steady state distributions) the initial or starting concentrations for a run may be relatively unimportant in that they do not affect the final quality predictions. For other studies (such as studies to determine the rate of salinity buildup or flushing) the starting concentrations significantly affect the final distribution and therefore must be carefully specified.

For verification runs in which historic quality conditions are simulated for a specific time period the initial quality distribution may be very critical and can be quite troublesome to specify unless adequate historic data are available. The importance of the starting concentrations in such runs and the difficulties associated with specifying them were discussed previously in Part II.

Although the initial concentrations do not affect the final steady state distribution predicted for a given set of hydraulic and quality inputs, the execution time required to achieve the steady state condition can be significantly affected. Obviously the closer the initial concentrations are to the steady state concentrations the shorter will be the required execution time. It is, of course, difficult to estimate a priori the steady state distribution of any particular constituent resulting from a given set of hydraulic and water quality inputs. It is possible to utilize steady state predictions from previous quality runs as the starting concentrations for new runs. A special feature of the model allows the adjustment of such initial concentrations within the program by applying a multiplication factor to the concentrations read from the input deck. The utilization of this feature can also reduce significantly the required execution time to attain steady state conditions. For example a run might typically be continued for fifteen tidal cycles and then examined to determine whether the predictions have converged to a steady state condition. If not, the predictions are extrapolated to an estimated steady state condition and multiplication factors computed which, when applied to the ending concentrations of the fifteen tidal cycle run, would result in the estimated steady state conditions. These factors are applied to the concentrations existing at each junction in a specified group of consecutively numbered junctions. The ending concentrations from the previous run are normally punched in a restart deck which is used to restart the run. The mulitplication factors are applied to the concentrations after they are read from the deck; therefore, no manual adjustment of the concentrations in the deck is required. This restart procedure is illustrated in Figure 47 showing, in (a) a restart multiplication factor greater than unity, and, in (b) a factor less than unity. Extrapolations such as illustrated should be determined for several locations throughout the system. In many cases the solution may have reached a steady state condition in one area while the concentrations in another area are increasing and those in yet another area decreasing. Separate factors are prepared for each of the latter two areas and applied to the appropriate sequences of junction numbers to increment the concentrations. In the event the factors over-adjust the concentrations the solution will converge to the steady state solution from the other direction, as illustrated in Figure 47(b).

Boundary Conditions. Frequently one of the most troublesome inputs is the specification of the quality conditions at the seaward boundary. Ideally the model boundary would be the ocean, a source and sink of known concentration. At upstream locations in an estuary the concentrations of most constituents vary with the flooding and ebbing of the tide and may also be a function of both the freshwater flow through the estuary and the waste loads on the system. Because each of these (tides, freshwater flow, and waste loads) is time dependent an estuary rarely approaches a steady state quality condition. The problem of specifying the boundary thus is one of estimating the tidal cycle variation of a constituent at the boundary location for a given freshwater flow through the system. In effect the boundary concentration specifies the concentration of the tidal flow entering the system on each flood tide. For simulation of historic conditions sufficient data must be available to establish the appropriate boundary conditions. For runs predicting future conditions or for comparing alternative waste disposal schemes it is necessary to estimate the quality levels which will result at the boundary for the specified set of hydraulic, tidal, and waste load conditions, i.e., the final results need to be known before the boundary can be specified. This dilemma can perhaps best be circumvented by the proper location of the boundary and by determining (through trial runs) the sensitivity of upstream predictions to the specified boundary conditions. Generally the effect of the boundary on upstream predictions decreases as the distance from the boundary increases. The model boundary should thus be located well downstream from any area of concern in the system and the specified boundary condition should be such that it not significantly bias the predictions in the areas of concern.

For certain constituents with little or no concentration gradient through the system the boundary can properly be specified as a constant value. For constituents (such as salinity) with a significant gradient through the system the concentration in the water entering through the seaward boundary will vary with the tidal phase. In such cases the boundary condition is defined by specifying a concentration for each quality time step over the full tidal cycle.

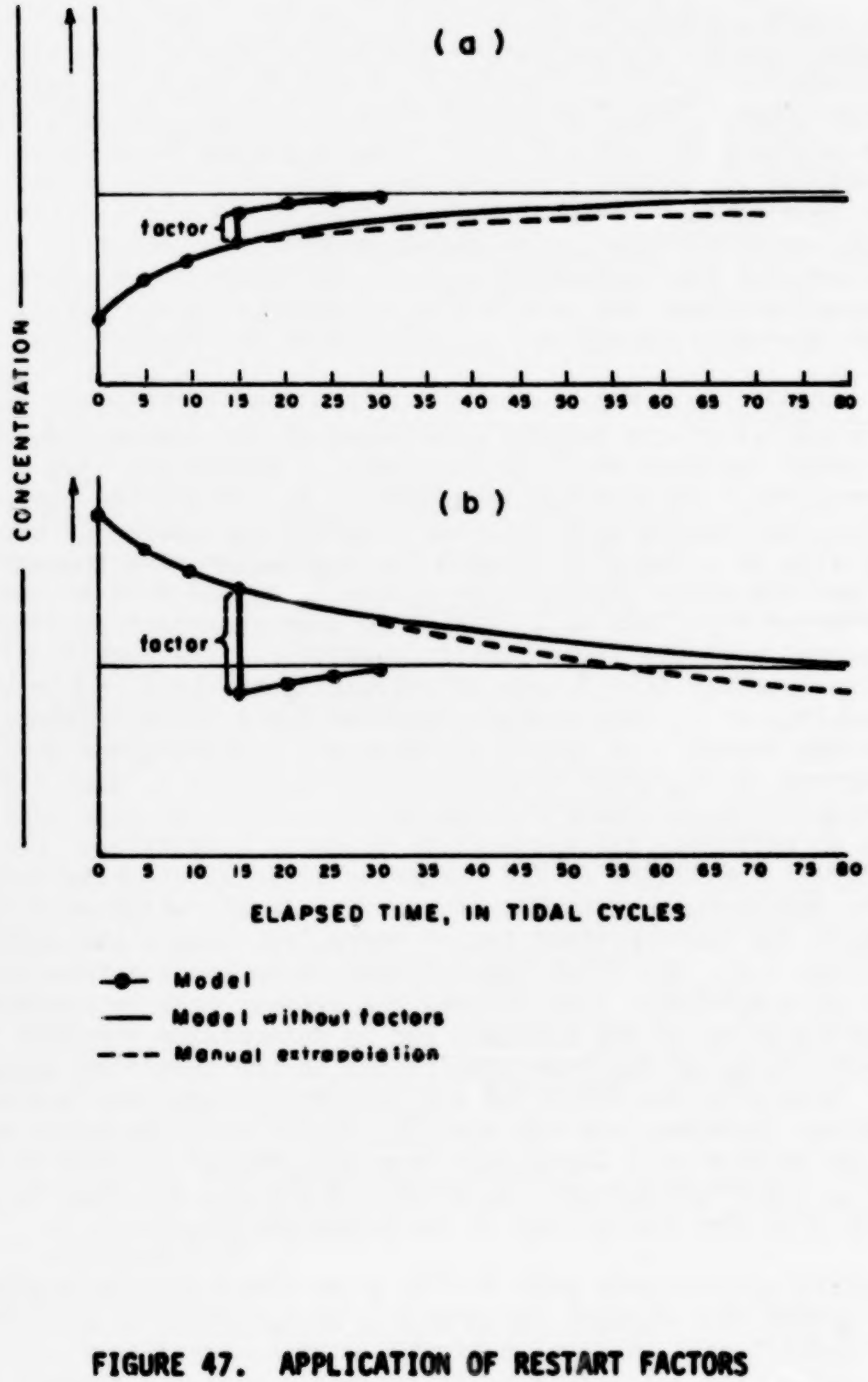


FIGURE 47. APPLICATION OF RESTART FACTORS

## Output Options and Control

A great deal of flexibility exists for specifying the type and quantity of printed output from the quality model. Two basic types of output are available: 1) predictions at specified junctions and at specified time steps to define the intratidal variation of a particular constituent, and 2) a summary in the form of the minimum, maximum, and average concentrations predicted at every junction in the system over a full tidal cycle. Output of both types is obtained only for selected tidal cycles through the run with output of the first type typically obtained at hourly (or once every two hours) intervals within the tidal cycle.

In addition to the printed output the quality predictions are stored on tape or disk at periodic intervals through the run to provide restart capability in the event execution terminates prematurely. If the run terminates normally the ending conditions are stored and are normally punched into a restart deck that can be used to extend the run.

Printout of the intratidal variation of the quality predictions is controlled through the specification of the four input parameters, IPRT, NQPRT, NEXTPR, and INTBIG. IPRT defines the initial print cycle in the quality run and NQPRT defines the print interval, in cycles (time steps). Printout which begins at cycle IPRT continues at the specified interval, NQPRT, for one complete tidal cycle and is then terminated. Printout begins again at cycle NEXTPR and is obtained each NQPRT cycles for a complete tidal cycle and is then again terminated. NEXTPR is then incremented by INTBIG to define the starting point for the third print sequence which again continues for a full tidal cycle. NEXTPR is incremented by INTBIG again, etc., etc. Generally IPRT is specified to obtain printout for the initial tidal cycle of a run to provide a check on the starting concentrations. Execution can then continue without output for as long as desired, as specified by NEXTPR. Printout for a full tidal cycle is then obtained at equal intervals for the remainder of the run as defined by INTBIG, i.e., INTBIG defines the interval between each print sequence.

Printout of the quality summary for a full tidal cycle is controlled through the specification of the three input parameters IWRITE, NEXTWR, and IWRINT. IWRITE is the quality cycle number at which the initial summary begins, NEXTWR is the quality cycle number at which the second summary begins, and IWRINT is the interval (in quality cycles) between all subsequent summaries.

Output can also include the summary of the quality predictions in any special manner desired, as programmed into subroutine ZONES. For example if it is desired to compute the mean constituent concentration in a certain zone or embayment of the system the junction numbers comprising the zone are programmed into the subroutine. Subroutine ZONES is thus unique for each system and can include as many special features as desired. Subroutine ZONES can be bypassed with the proper specification of the control variable KZOP.

An option is also provided to suppress the printout of the statement generated whenever the concentration drops below zero (depletion correction). For runs such as the simulation of a prototype dye release, wherein the initial concentrations at every junction in the network may be zero, many such depletion corrections will occur and it is desirable to suppress the printed statement. During the initial time steps of such a simulation a quality gradient begins to form with the maximum concentration existing at the discharge point of the dye. As the solution progresses the dye continues to build up and spread to adjacent junctions. At any given time there are several junctions which lie just beyond the plume of dye, i.e., which remain at zero concentration but which are immediately adjacent to a junction which received dye. In such cases there is an apparent concentration gradient between the junctions and, when the flow direction is from the junction with zero concentration to the junction with an above-zero concentration, the program will compute an above-zero concentration at the quarter-point and remove mass from the upstream junction, creating a negative concentration. The negative concentration is corrected (i.e., assigned a zero value) and, unless suppressed, a statement of the correction will be printed. As the peripheral edge of the dye spreads more and more junctions are affected. Printout of the depletion correction can be suppressed in such runs by the proper specification of the control variable KDCOP.

For runs in which dissolved oxygen is one of the constituents considered the printout of the depletion correction statement should not be suppressed as the occurence of a negative concentration of dissolved oxygen may indicate anaerobic conditions. Care should be exercised in interpreting depletion corrections however, because the depletion may be caused by a slightly unstable solution technique and may not be an indication that the dissolved oxygen has been biochemically depleted.

### Interpretation of Output

Output from subroutine QUALEX and ZONES can significantly reduce the manual effort required in the interpretation of model predictions. For example in determining whether a solution has reached steady state throughout the system it is only necessary to compare the maximum (the minimum or average could also be used) concentrations listed for representative junctions for the last tidal cycle of the run with those listed for the same junctions for the previous tidal cycle summarized (usually five to ten tidal cycles earlier). If the change in concentration at each junction is within acceptable limits the solution can be considered at steady state. For the San Francisco Bay system a solution was generally considered at steady state if the concentration change at each junction over the last ten tidal cycles of the run did not exceed three percent. If the change in concentration at any junction is greater than the acceptable limit the concentration can be extrapolated to steady state and an appropriate restart factor determined as discussed in an earlier section.

In cases wherein model predictions are being compared to prototype data it may be necessary to refer back to the hydraulic solution to assure that the comparisons are for the proper tidal phase, e.g., if slack water concentrations are being compared it is necessary to determine that the model prediction is representative of slack water. The quality printout defining the intratidal variation includes the tidal stage for each junction so that the velocity data associated with that tidal stage can be determined from the hydraulic run (provided printout was provided for the junctions in question).

## Potential Implementation Difficulties

In its present form several of the variables used in the quality program share common storage locations (as specified in the EQUIVALENCE statement) to reduce overall storage requirements. If program logic is altered or if DIMENSION changes are made the programmed EQUIVALENCE statement may also require modification.

For quality studies wherein the hydraulic or waste load conditions change during the period of study it may be desirable to break the quality solution into two or more parts with a different hydraulic solution utilized for each part. In such cases the transition from one part to the next can introduce difficulties, particularly if different tidal conditions are utilized for the two parts. At the end of each run the ending concentrations of each constituent are stored on tape or are punched into a restart deck. It is thus the concentration and not the total mass which is carried over if the run is extended. It is therefore important that the volume of the system at the start of a continuation run be the same as the volume existing at the end of the previous run. If a run is extended utilizing the same hydraulic solution the restart point on the tide will be identical to the previous stopping point (as specified by NRSTRT and NTAG), assuring the proper starting mass of each constituent in the system. If the extension of a run is based on a different hydraulic solution it is important that the starting point on the new tide be as close as possible to the ending point on the previous tide (both tidal stage and phase) so that the starting volume (and hence the initial mass of each constituent) is appropriate.

## Execution Time

The time required to execute the quality program is dependent on the computer used (and the accounting procedure utilized), the size of the network, the number of constituents included in the simulation, the time step utilized, the overall length of the simulation, and the amount of printout specified. When considering the overall cost to execute the quality program it is necessary to realize that the quality program cannot be executed without a proper hydraulic input, i.e., the hydraulic program must first be solved to create the necessary hydraulic input. Typical execution times for the quality program are summarized in Table 7. A CDC 6600 computer was utilized for the solutions in each case. Experience indicates comparable execution times on an IBM 360/65 would be approximately two to three times greater than those indicated. Inconsistencies apparent in the execution times may be attributable to the difference in the amount of output obtained for each run.

TABLE 7. EXECUTION TIMES FOR QUALITY MODEL

| Size of System | | Time Step Utilized (Minutes) | Number of Constituents | Length of Run (days) | Execution Time (minutes) |
|---|---|---|---|---|---|
| Junctions | Channels | | | | |
| 112 | 170 | 15 | 3 | 20 | 5 |
| 112 | 170 | 15 | 1 | 20 | 3 |
| 112 | 170 | 7.5 | 1 | 20 | 7 |
| 830 | 1050 | 30 | 1 | 28 | 14 |
| 830 | 1050 | 15 | 2 | 10 | 10 |
| 830 | 1050 | 30 | 3 | 15 | 8 |
| 830 | 1050 | 30 | 3 | 20 | 10 |

### Description and Format of Program Inputs (DYNQUA)

The symbols and format used in the following description of the input data deck for DYNQUA are identical to those used for program DYNHYD on page 119.

| Card | Columns | Name | Description |
|---|---|---|---|
| 1 | 1-5R | NJ | Total number of junctions in system. Identical to NJ in program DYNHYD. |
| | 6-10R | NC | Total number of channels in system. Identical to NC in program DYNHYD. |
| | 1-15R | NSTART | Cycle number from hydraulic solution which is the initial cycle on the hydraulic extract input tape 3. Identical to NSTART in Subroutine HYDEX. |

| **Card** | **Column** | **Name** | |
|---|---|---|---|
| | 16-20R | NSTOP | Cycle number from hydraulic solution which is the final cycle on the hydraulic extract tape 3. Identical to NSTOP in Subroutine HYDEX. |
| | 21-25R | NODYN | Number of hydraulic time steps per quality time step. Identical to NODYN in Subroutine HYDEX. |
| 2 | 1-5R | NRSTRT | Cycle number on input tape 3 (hydraulic extract tape) at which quality run is to begin (NSTART $\leq$ NRSTRT $\leq$ NSTOP). |
| | 6-10R | INCYC | Initial quality cycle number. For first run of a series INCYC should equal 1. For continuation or restart runs INCYC should equal x+1 where x equals the number of cycles completed previously. |
| | 11-15R | NQCYC | Total number of quality cycles to be completed. NOCYC must include all cycles previously completed, i.e., NQCYC equals INCYC plus the additional cycles to be completed in the current run. |
| | 16-20R | KZOP | Control option for calling Subroutine ZONES. KZOP must equal 1 to call ZONES or 2 to bypass ZONES. |
| | 21-25R | KDCOP | Control option for printout of depletion correction message. KDCOP must equal 1 for printout or 2 to delete printout of depletion correction message. |
| | 26-30R | NTAG | Counter which is reset to zero at the completion of each full tidal cycle. NTAG varies between zero and NSPEC where NSPEC is the number of quality cycles per tidal cycle. |

| Card | Column | Name | Description |
|---|---|---|---|
|  | 31-40R. | CDIFFK | Constant for computing diffusion coefficient. |
| 3 | 1-5R | IPRT | Initial print cycle (IPRT must be $\geq$ INCYC). Printout begins for the first time at cycle IPRT and continues for one full tidal cycle at intervals of NQPRT cycles (time steps). |
|  | 6-10R | NQPRT | Number of quality cycles (time steps) between printouts. NQPRT normally is such that printout is obtained at hourly or two-hour intervals. |
|  | 11-15R | NEXTPR | Quality cycle number at which printout begins for second time and continues at NQPRT intervals for a full tidal cycle. |
|  | 16-20R | INTBIG | Interval, in quality cycles (time steps), between the start of printouts over a full tidal cycle. NEXTPR is increased by INTBIG at the completion of each full tidal cycle of output. |
|  | 21-25R | IWRITE | Cycle number at which storage of quality data on tape or disk begins for the first time. Data for each time step over a full tidal cycle is passed to Subroutine QUALEX. |
|  | 26-30R | NEXTWR | Cycle number at which storage of quality data on tape or disk begins for the second time. |
|  | 31-35R | IWRINT | Interval, in quality cycles (time steps), between the storage of data on tape or disk. NEXTWR is increased by IWRINT at the completion of storing data for a full tidal cycle. Quality summaries are obtained at IWRINT intervals. |

| Card | Column | Name | Description |
|---|---|---|---|
| 4 | 1-80 | ALPHA(I) | Alphanumeric identifier for quality run--printed as heading for output (I=41,60 with A4 format). |
| 5 | 1-80 | ALPHA(I) | Alphanumeric identifier for quality run--printed as heading for output (I=61,80 with A4 format) |
| 6 | 1-5R | NUMCON | Number of quality constituents considered in the run (1 ≤ NUMCON ≤ 5). |
| 7 | 1-5R | NCONDK(I) | Number (1 through 5) of the first nonconservative constituent, e.g., if the first two constituents are conservative and the third nonconservative then NCONDK(1)=3. If none of the NUMCON constituents are treated as nonconservative NCONDK(1) must be set equal to zero. |
|  | 6-10R | NCONOX(1) | Number of the constituent which is dissolved oxygen and which is associated with the nonconservative constituent (BOD) assigned to NCONDK(1). If dissolved oxygen is not being considered NCONOX(1) must be set equal to zero. |
|  | 11-15R | NCONDK(2) | Number of the second nonconservative constituent considered. If only one (or none) of the constituents being considered is nonconservative NCONDK(2) must equal zero. |
|  | 16-20R | NCONOX(2) | Number of the constituent (if any) associated with the constituent assigned to NCONDK(2). |
|  | 21-25R | NCONDK(3) | Number of the third nonconservative constituent. NCONDK(3) must equal zero if two or fewer nonconservative constituents are considered. |

| Card | Column | Name | Description |
|---|---|---|---|
| | 26-30R | NCONOX(3) | Number of the constituent (if any) associated with the constituent assigned to NCONDK(3). |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | 41-45R | NCONDK(5) | Number of the fifth nonconservative constituent. NCONDK(5) must equal zero if four or fewer nonconservative constituents are considered. |
| | 46-50R | NCONOX(5) | Number of the constituent (if any) associated with the constituent assigned to NCONDK(5). |
| *7a | 1-10R. | DECAY(1) | Decay coefficient (base e, per day) applied to the nonconservative constituent assigned to NCONDK(1), i.e., to the first nonconservative constituent. |
| | 11-20R. | REOXK(1) | Reoxygenation coefficient (base e, per day) applied to the DO constituent (if any) assigned to NCONOX(1). |
| | 21-30R. | CSAT(1) | Dissolved oxygen saturation concentration, in mg/l, for the DO constituent assigned to NCONOX(1). |
| | ..... | ..... | ..... |
| | 1-10R. | DECAY(2) | Decay coefficient (base e, per day) applied to second nonconservative constituent. |
| | 11-20R. | REOXK(2) | Reoxygenation coefficient (base e, per day) applied to the DO constituent (if any) assigned to NCONOX(2). |
| | 21-30R. | CSAT(2) | DO saturation concentration, in mg/l, for DO constituent assigned to NCONOX(2). |

| Card | Column | Name | Description |
|---|---|---|---|
| | .... | .... | .... |
| | .... | .... | .... |
| | 1-10R. | DECAY(5) | Decay coefficient applied to fifth nonconservative constituent. |
| | 11-20R. | REOXK(5) | Reoxygenation coefficient applied to the DO constituent (if any) assigned to NCONOX(5). |
| | 21-30R. | CSAT(5) | DO saturation concentration for constituent assigned to NCONOX(5). |
| *8 | 1-80 | ALPHA(I) | Alphanumeric identifier, one card for each constituent (I=121, NALPHA where NALPHA = NUMCON*20). |
| 9 | 1-10R. | CLIMIT(1) | Concentration limit for first constituent. Run is aborted if concentration exceeds CLIMIT. |
| | 11-20R. | CLIMIT(2) | Concentration limit for second constituent. |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | 41-50R. | CLIMIT(5) | Concentration limit for fifth constituent. |
| 10 | 1-5R | NUNITS | The number of units for which waste water return factors are applied. A unit consists of two junctions at which diversions occur and two junctions at which the waste water from those diversions is returned. The same return factor is applied to both junctions in each pair. |
| *10a | 1-3R | JDIV1(1) | The junction number of the first diversion in unit 1. |

| Card | Column | Name | Description |
|---|---|---|---|
| | 4-7R | JDIV2(1) | The junction number of the second diversion in unit 1. |
| | 9-11R | JRET1(1) | The junction number of the first return flow in unit 1. JRET1(1) is paired with JDIV1(1). |
| | 12-15R | JRET2(1) | The junction number of the second return flow in unit 1. JRET2(1) is paired with JDIV2(1). |
| | 16-20R. | RETFAC(1,1) | Return factor for unit 1 and constituent 1. |
| | 21-28R. | CONST(1,1) | Constant applied to junction in unit 1 for constituent 1. |
| | 29-33R. | RETFAC(1,2) | Return factor for unit 1 and constituent 2. |
| | 34-41R. | CONST(1,2) | Constant for unit 1 and constituent 2. |
| | ⋮ | ⋮ | ⋮ |
| | 68-72R. | RETFAC(1,5) | Return factor for unit 1 and constituent 5. |
| | 73-80R. | CONST(1,5) | Constant for unit 1 and constituent 5. |
| | .... | .... | .... |
| | 1-3R | JDIV1(2) | Junction number of the first diversion in unit 2. |
| | 4-7R | JDIV2(2) | Junction number of the second diversion in unit 2. |
| | 8-11R | JRET1(2) | Junction number of first return flow in unit 2. |
| | 12-15R | JRET2(2) | Junction number of second return flow in unit 2. |

| Card | Column | Name | Description |
|---|---|---|---|
| | 16-20R. | RETFAC(2,1) | Return factor for unit 2 and constituent 1. |
| | 21-28R. | CONST(2,1) | Constant for unit 2 and constituent 1. |
| | ⋮ | ⋮ | ⋮ |
| | 68-72R. | RETFAC(2,5) | Return factor for unit 2 and constituent 5. |
| | 73-80R. | CONST(2,5) | Constant for unit 2 and constituent 5. |
| | .... | .... | .... |
| | .... | .... | Card 10a is repeated NUNITS times, i.e., one card per unit. If NUNITS equals zero, no cards in this series are required. |
| *11 | 1-5R | J | Junction number. Read as dummy variable JJ to check card sequence. |
| | 6-15R. | QINWQ(J) | Flow rate of waste water discharge or diversion at junction J, in cfs. QINWQ(J) must be negative for a waste water discharge and positive for a diversion. |
| | 16-25R. | C(J,1) | Initial concentration assigned to junction J for the first constituent. |
| | 26-35R. | CSPEC(J,1) | The specified concentration of the first constituent in the waste water discharge QINWQ(J) at junction J. If QINWQ(J) is zero or is positive (indicating a withdrawal) CSPEC(J,1) will be ignored. |
| | 36-45R. | C(J,2) | Initial concentration assigned to junction J for the second constituent (if more than one constituent is considered). |

| Card | Column | Name | Description |
|---|---|---|---|
| | 46-55R. | CSPEC(J,2) | The specified concentration of the second constituent in the waste water discharge QINWQ(J) at junction J. |
| | 58-65R. | C(J,3) | Initial concentration assigned to junction J for the third constituent. (If more than two constituents are considered). |
| | 66-75R. | CSPEC(J,3) | The specified concentration of the third constituent in the waste water discharge QINWQ(J) at junction J. |
| | .... | .... | .... |
| | .... | .... | Card 11 is repeated NJ times, i.e., one card for each junction in the network. |
| *11a | 1-5R | J | Junction number. Cards in this series are required only if more than three constituents are being considered simultaneously. These cards must also be in sequence, beginning with junction 1. |
| | 6-15R. | C(J,4) | Initial concentration assigned to junction J for the fourth constituent. |
| | 16-25R. | CSPEC(J,4) | The specified concentration of the fourth constituent in the waste water discharge QINWQ(J) of junction J. |
| | 26-35R. | C(J,5) | Initial concentration assigned to junction J for the fifth constituent. |
| | 36-45R. | CSPEC(J,5) | The specified concentration of the fifth constituent in the waste water discharge QINWQ(J) at junction J. |
| | .... | .... | .... |

| Card | Column | Name | Description |
|---|---|---|---|
| | .... | .... | Card 11a is repeated NJ times, i.e., one card per junction. |
| 12 | 1-5R | NGROUP(1) | The number of groups (up to 10) of junction numbers for which it is desired to increment the initial concentrations of the first constituent which were previously read as input. There is no limit (up to NJ) to the number of junctions comprising a group but the numbers must be consecutive. |
| *12a | 1-5R. | FACTR(1,1) | Multiplication factor to be applied to the initial concentration of the first constituent at those junctions in the first group. This card will not be required if NGROUP(1)=0. |
| | 6-10R | NJSTRT(1,1) | The first (lowest) junction number in the sequence of junctions comprising the first group for the first constituent. |
| | 11-15R | NJSTOP( 1,1) | The final (highest) junction number in the sequence of junctions comprising the first group for the first constituent. |
| | 16-20R. | FACTR(1,2) | Multiplication factor to be applied to the initial concentration of the first constituent at those junctions in the second group (if more than one group is specified). |
| | 21-25R | NJSTRT(1,2) | The first junction number in the sequence of junctions comprising the second group for the first constituent. |
| | 26-30R | NJSTOP(1,2) | The final junction number in the sequence of junctions comprising the second group for the first constituent. |

| Card | Column | Name | Description |
|---|---|---|---|
| | ⋮ | ⋮ | ⋮ |
| | 61-65R. | FACTR(1,5) | Multiplication factor to be applied to the initial concentration of the first constituent at those junctions in the fifth group (if more than four groups are specified). |
| | 66-70R | NJSTRT(1,5) | The first junction number in the fifth group for the first constituent. |
| | 71-75R | NJSTOP(1,5) | The final junction number in the fifth group for the first constituent. |
| | .... | .... | .... |
| | 1-5R. | FACTR(1,6) | Multiplication factor to be applied to the initial concentration of the first constituent at those junctions in the sixth group. This card is required only if more than five groups were specified, i.e., NGROUP(1) >5. |
| | 6-10R | NJSTRT(1,6) | The first junction number in the sixth group for the first constituent. |
| | 11-15R | NJSTOP(1,6) | The final junction number in the sixth group for the first constituent. |
| | ⋮ | ⋮ | ⋮ |
| | 61-65R. | FACTR(1,10) | Multiplication factor to be applied to initial concentrations of the first constituent at those junctions in the tenth group. |

| Card | Column | Name | Description |
|---|---|---|---|
| | 66-70R | NJSTRT(1,10) | The first junction number in the tenth group for the first constituent. |
| | 71-75R | NJSTOP(1,10) | The final junction number in the tenth group for the first constituent. |
| 13a | 1-5R | NGROUP(2) | The number of groups (up to 10) of junction numbers for which it is desired to increment the initial concentrations of the second constituent. This card will not be required if NUMCON = 1. |
| | .... | .... | If NGROUP(2) = 0 no additional cards in this series are required. If NGROUP(2)>0 one or two additional cards are required following card 13a with values for FACTR, NJSTRT, and NJSTOP for up to five groups on the first of these cards and values for the sixth through tenth groups (if needed) on the second card. The format is identical to cards *12a. |
| 14a | 1-5R | NGROUP(3) | The number of groups (up to 10) of junction numbers for which it is desired to increment the initial concentrations of the third constituent. This card is not required if NUMCON ≥ 2. |
| | .... | .... | If NGROUP(3)=0 no additional cards in this series are required. If NGROUP(3) >0 one or two additional cards are required following card 14a with values for FACTR, NJSTRT, and NJSTOP for the groups desired for the third constituent. The format is identical to cards *12a. |

| Card | Column | Name | Description |
|---|---|---|---|
| 15a | 1-5R | NGROUP(4) | The number of groups of junction numbers for which it is desired to increment the initial concentrations of the fourth constituent. This card is not required if NUMCON ≤3. |
|  | .... | .... | If NGROUP(4)=0 no additional cards in this series are required. If NGROUP(4) >0 one or two additional cards are required following card 15a to specify the values for FACTR, NJSTRT, and NJSTOP for the groups desired for the fourth constituent. The format is identical to cards *12a. |
| 16a | 1-5R | NGROUP(5) | The number of groups of junction numbers for which it is desired to increment the initial concentrations of the fifth constituent. This card is not required if NUMCON ≤4. |
|  | .... | .... | If NGROUP(5)=0 no additional cards in this series are required. If NGROUP(5) >0 one or two additional cards are required following card 16a to specify the values for FACTR, NJSTRT, and NJSTOP for the groups desired for the fifth constituent. The format is identical to cards *12a. |
| 17 | 1-5R | KBOP(1) | Control option for specifying concentration of first constituent at boundary. If boundary concentration is constant over full tidal cycle KBOP(1)=1, if variable over tidal cycle KBOP(1)=2. |
|  | 6-10R | KBOP(2) | Control option for specifying concentration of second constituent at boundary. KBOP(2)=1 for constant boundary, or 2 for variable boundary. |

| Card | Column | Name | Description |
|---|---|---|---|
| | .<br>.<br>.<br>. | .<br>.<br>.<br>. | .<br>.<br>.<br>. |
| | 21-25R | KBOP(5) | Control option for specifying concentration of fifth constituent at boundary. KBOP(5)=1 for constant boundary, or 2 for variable boundary. |
| 18 | 1-5R | NSPEC | The number of quality time steps per tidal cycle. |
| *19 | 1-10R. | CIN(1,1) | The boundary concentration specified for the first constituent for the initial time step. If KBOP(1)=1 then CIN(1,1) is the constant boundary concentration and no additional specification is required for the first constituent. |
| | 11-20R. | CIN(1,2) | The boundary concentration specified for the first constituent for the second time step if KBOP(1)=2. |
| | .<br>.<br>.<br>. | .<br>.<br>.<br>. | .<br>.<br>.<br>. |
| | 61-70R | CIN(1,7) | The boundary concentration specified for the first constituent for the seventh time step. |
| | .... | .... | .... |
| | .... | .... | Card 19 is repeated as necessary to specify all NSPEC boundary concentrations for the first constituent. |
| | .... | .... | .... |

| Card | Column | Name | Description |
|---|---|---|---|
| *20a | 1-10R. | CIN(2,1) | The boundary concentration specified for the second constituent for the first time step. If KBOP(2)=1 then CIN(2,1) is the constant boundary concentration and no additional specification is required for the second constituent. |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | .... | .... | Card 20a is repeated as necessary to specify all NSPEC boundary concentrations for the second constituent. If NUMCON=1 the card series 20a is not required. |
| | .... | .... | .... |
| *21a | 1-10R. | CIN(3,1) | The boundary concentration specified for the third constituent for the initial time step. If KBOP(3)=1 no additional specification is required for the third constituent. If NUMCON ≤ 2 this card series is not required. |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | . | . | . |
| | .... | .... | .... |
| | .... | .... | Card 21a is repeated as necessary to specify all NSPEC boundary concentrations for the third constituent. |
| *22a | 1-10R. | CIN(4,1) | The boundary concentration specified for the fourth constituent for the initial time step. If KBOP(4)=1 no additional specification is required for the fourth constituent. If NUMCON≤3 this card series is not required. |

| Card | Column | Name | Description |
|---|---|---|---|
|  | .<br>.<br>.<br>. | .<br>.<br>.<br>. | .<br>.<br>.<br>. |
|  | .... | .... | .... |
|  | .... | .... | Card 22a is repeated as necessary to specify all NSPEC boundary concentrations for the fourth constituent. |
|  | .... | .... | ..... |
| *23a | 1-10R | CIN(5,1) | The boundary concentration specified for the fifth constituent for the initial time step. If KBOP(5)=1 no additional specification is required for the fifth constituent. If NUMCON≤4 this card series is not required. |
|  | .<br>.<br>.<br>. | .<br>.<br>.<br>. | .<br>.<br>.<br>. |
|  | .... | .... | .... |
|  | .... | .... | Card 23a is repeated as necessary to specify all NSPEC boundary concentrations for the fifth constituent. |
| 24 | 1-5R | NOPRT | The total number of junctions for which printout is desired. |
| *25 | 1-5R | JPRT(1) | Junction number for which printout is desired. |
|  | 6-10R | JPRT(2) | Junction number for which printout is desired. |
|  | .<br>.<br>.<br>. | .<br>.<br>.<br>. | .<br>.<br>.<br>. |

| Card | Column | Name | Description |
|---|---|---|---|
| | 66-70R | JPRT(14) | Junction number for which printout is desired. |
| | .... | .... | .... |
| | .... | .... | Card 25 is repeated as necessary to specify all junctions (up to 50) for which printout is desired (fourteen junction numbers per card). |

## Variables Internal to Program DYNQUA

| Variable | Description |
|---|---|
| Tape 3 | Hydraulic extract tape which was created by subroutine HYDEX in the hydraulic run and which serves as the basic hydraulic input to the quality program. |
| Tape 5 | Indicates card input. |
| Tape 6 | Indicates printed output. |
| Tape 9 | Indicates punched output. |
| Tape 10 | Scratch tape or disk used to store quality predictions during program execution. Data stored on unit 10 are summarized in subroutine QUALEX and ZONES. |
| K | Defines the number of quality time steps comprising a full tidal cycle (also equals NSPEC). |
| ICYCTF | Cycle number, read from tape 3, from the transient flow (hydraulic) program. |
| YNEW(J) | A new name for the head at junction J to differentiate it from the head at the same junction at another time step. |

| Variable | Description |
|---|---|
| Q(N)<br>V(N)<br>QNET(N)<br>ALPHA(I)<br>DELT<br>CN(N)<br>R(N)<br>B(N)<br>CLEN(N)<br>Y(J)<br>AREAS(J)<br>QIN(J)<br>NCHAN(J,K)<br>AREA(N)<br>NJUNC(N,I) | These variables have been defined previously for the hydraulic program DYNHYD. They are stored on tape 3 for input to DYNQUA. |
| DELTQ1 | The quality time step, in hours. |
| DELTQ2 | The print interval, in hours. |
| QDECAY(K) | The coefficient, which when applied to BOD, defines the BOD exerted, or equivalently, the mass of oxygen utilized. |
| NALPHA | Defines the total number of ALPHA(I) values required. |
| KDONE | A flag which is set equal to one whenever a full tidal cycle of quality data has been stored on tape 10. When this occurs subroutine QUALEX is called and KDONE is reinitialized to zero. |
| MARK1 | The initial quality cycle number of the data stored on tape 10, i.e., the start of a full tidal cycle of quality data. |
| MARK2 | The final quality cycle number of the data stored on tape 10, i.e., the end of a full tidal cycle of quality data. |
| DELTQ | Time step for quality solution, in seconds. |
| NCOUNT | A counter used to determine when a full tidal cycle of printout has been obtained. |
| KOUNTT | A counter used to determine when a full tidal cycle of quality data has been stored on tape 10. |

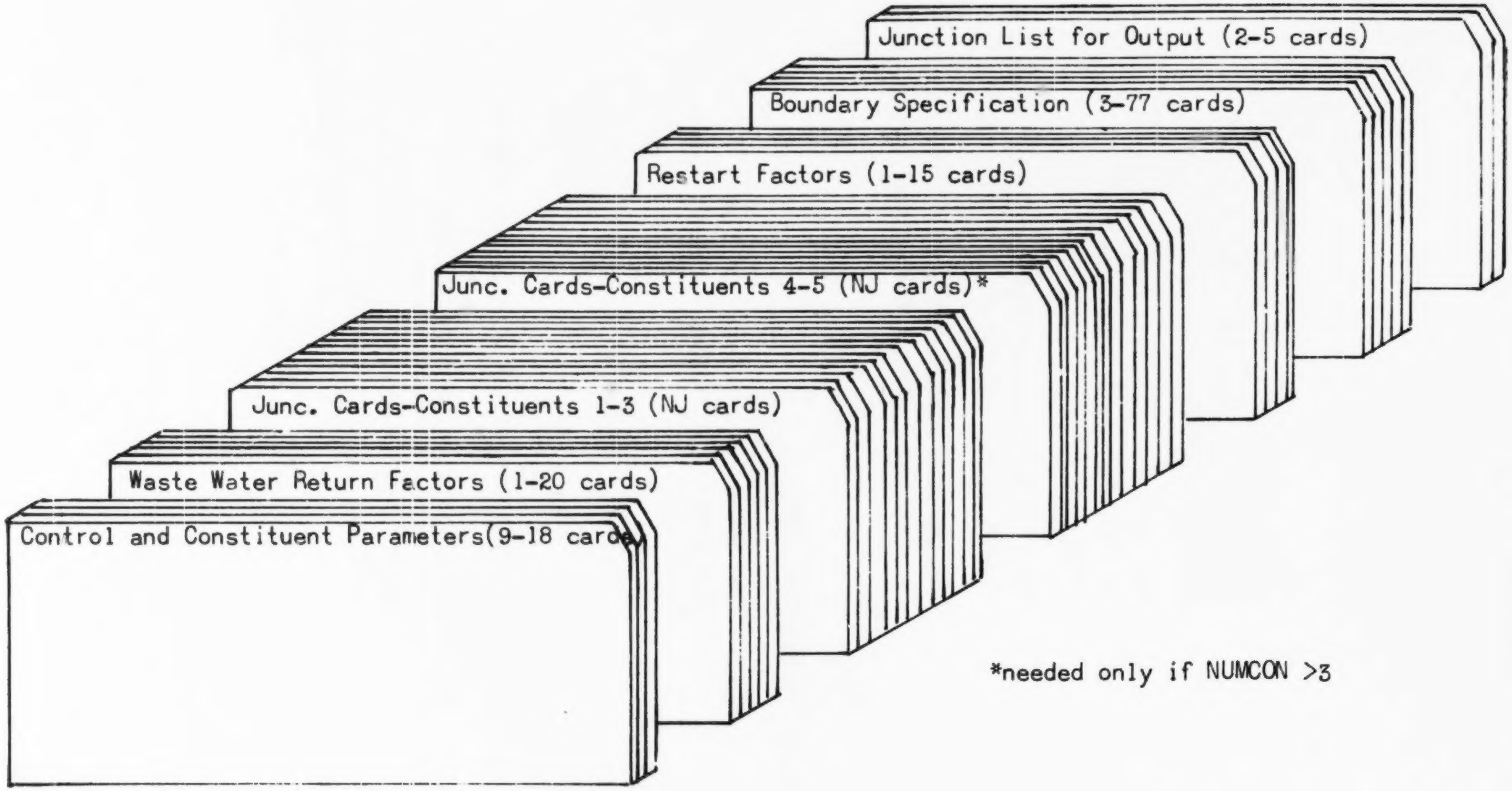
| Variable | Description |
|---|---|
| NTEMP | Cycle number which marks the end of the record on tape 3 and signals a REWIND command. |
| AVOL(J) | The mean volume of junction J, in cubic feet. |
| VOL(J) | Volume of junction J, in cubic feet. |
| CMASS(J,K) | Mass of constituent K at junction J. |
| DIFFK(N) | Diffusion coefficient in channel N. |
| VOLQIN(J) | The volume of the diversion or waste water discharge QIN(J) during each time step. |
| ICYC | Cycle number (iteration) during execution of quality program. |
| NOCYCC | Number of quality cycles (time steps) completed at any instant during execution. |
| VOLFLW | Flow volume in a given channel during a full time step. |
| FACTOR | Factor used to determine quarter-point concentration for advective transport. |
| QGRAD | Quality gradient existing in a given channel. |
| CONC | The concentration used in the advective transport equation. |
| ADMASS | The mass of a given constituent advected from one junction to another. |
| DIMASS | The mass of a given constituent transferred from one junction to another by diffusion. |
| HOURS | Total elapsed hours of prototype simulation. |
| KDAYS | Total elapsed days of prototype simulation. |

## Variables Internal to Subroutine QUALEX

| Variable | Description |
|---|---|
| ICYCQ | Cycle number from quality program which was stored on tape 10. |
| CX(J,K) | The concentration of constituent K at junction J. Read as CX(J,K) from tape 10 to differentiate from C(J,K) in the calling program. |
| CAVE(J,K) | The average concentration of constituent K at junction J computed over a full tidal cycle. |
| CMIN(J,K) | The minimum concentration of constituent K at junction J over a full tidal cycle. |
| CMAX(J,K) | The maximum concentration of constituent K at junction J over a full tidal cycle. |

## Variables Internal to Subroutine ZONES

| | |
|---|---|
| TVOL1<br>TVOL2<br>.<br>.<br>.<br>.<br>TVOL6 | The total mean volumes of zones 1,2,...6 The zones are unique for each estuary studied. |
| TVOLT | The mean volume of the total estuary. |
| SAT | Total surface area of the estuary. |
| TLBSC1(I)<br>TLBSC2(I)<br>.<br>.<br>.<br>.<br>TLBSC6(I) | Total mass of constituent I in zones 1, 2, ...., 6 at mean tide. |
| TLBSCT(I) | Mass of constituent I in total estuary at mean tide. |


Junction List for Output (2-5 cards)
Boundary Specification (3-77 cards)
Restart Factors (1-15 cards)
Junc. Cards-Constituents 4-5 (NJ cards)*
Junc. Cards-Constituents 1-3 (NJ cards)
Waste Water Return Factors (1-20 cards)
Control and Constituent Parameters(9-18 cards)

*needed only if NUMCON >3

FIGURE 48. SAMPLE DATA DECK MAKEUP--PROGRAM DYNQUA

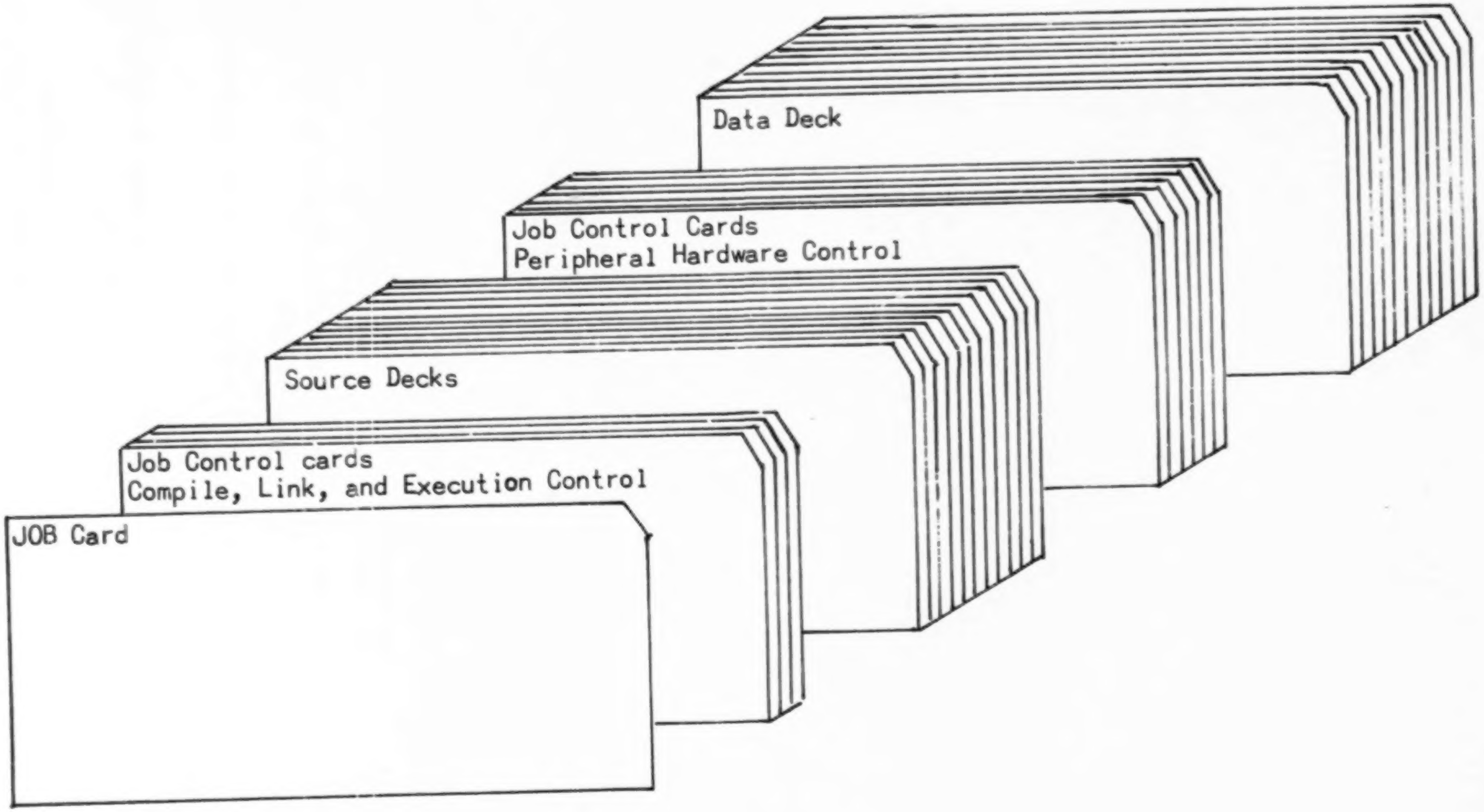

Data Deck
Job Control Cards
Peripheral Hardware Control
Source Decks
Job Control cards
Compile, Link, and Execution Control
JOB Card

FIGURE **49.** SAMPLE JOB DECK MAKEUP - PROGRAM DYNQUA

| Variable | Description |
|---|---|
| CAVE1(I)<br>CAVE2(I)<br>.<br>.<br>.<br>.<br>CAVE6(I) | The mean concentration of constituent I in zones 1, 2, ...., 6 at mean tide. |
| CAVET(I) | The mean concentration of constituent I in total estuary at mean tide. |

## REGRESSION ANALYSIS PROGRAM (REGAN)

The required boundary input for the hydraulic program includes the specification of the water surface elevation at the model boundary for each time step in the solution. This is accomplished by specifying the period of the tide plus the seven coefficients $A_1$ through $A_7$ in the relationship:

$$Y = A_1 + A_2 \text{ Sin } (\omega t) + A_3 \text{ Sin } (2\ \omega t) + A_4 \text{ Sin } (3\ \omega t) +$$
$$A_5 \text{ Cos } (\omega t) + A_6 \text{ Cos } (2\ \omega t) + A_7 \text{ Cos } (3\ \omega t)$$

which appeared before as equation 13.

The coefficients are determined by a least squares regression analysis (REGAN) on a specified number of equally spaced data points over the desired tidal cycle. Normally points on a one-half or one hour basis are adequate for the analysis.

### Description and Format of Program Inputs (REGAN)

| Card | Columns | Name | Description |
|---|---|---|---|
| 1 | 1-3R | KO | Recycle option. KO = 1 to read new data set. |
|  | 4-6R | NI | Total number of points specified over tidal cycle. |
|  | 7-9R | NJ | Number of coefficients in trigonometric equation. |
|  | 10-12R | MAXIT | Maximum number of iterations required in the analysis (normally less than 8). |

| Card | Column | Name | Description |
|---|---|---|---|
|  | 1-24R. | DELTA | Maximum value of residual allowed (0.0001 is typically used). Will not be exceeded unless the number of iterations exceeds MAXIT. |
|  | 25-36R. | PERIOD | The period of the tide, in hours. |
|  | 37-48R. | ALAG | Variable available to shift time scale on specified inputs (normally equals zero). |
|  | 49-60R. | BLAG | Variable available to shift phase angle in trigonometric relationship (normally equals zero). |
| 2* | 1-8R. | T(1) | Time, in hours, of first specified data point on input tide. |
|  | 9-16R. | Y(1) | Elevation, in feet, of first specified data point on input tide (referenced to model datum). |
|  | 17-24R. | T(2) | Time, in hours, of second specified data point on input tide. |
|  | 25-32R. | Y(2) | Elevation, in feet, of second specified data point on input tide. |
|  | .<br>.<br>.<br>. | .<br>.<br>.<br>. |  |
|  | 49-56R. | T(4) | Time, in hours, of fourth specified data point on input tide. |
|  | 57-64R. | Y(4) | Elevation, in feet, of fourth specified data point on input tide. |
|  | .... | .... | .... |
|  | 1-8R. | T(5) | Time, in hours, of fifth specified data point on input tide. |
|  | 9-16R. | Y(5) |  |
|  | .... | .... | Card 2 is repeated as required to include all NI values of T(I) and Y(I). |

## DATA PREPARATION PROGRAM (DATAP)

The data preparation program was developed to reduce the input data requirements for the hydraulic model. For the San Francisco Bay-Delta system the program computed agricultural consumptive use, evaporation, precipitation, and soil moisture depletion or accretion. The program combines these various components into a net accretion or depletion at each junction in the network and punches the input data deck for the hydraulic program.

The program developed for the San Francisco Bay system is quite specific and lacks general applicability to other estuarial systems. The program presented herein is a generalized version with provisions for computing monthly evaporation and precipitation and combining them with a specified inflow or withdrawal to obtain a net accretion or depletion at each junction.

Input requirements for the program include the surface area of each junction, any specified inflow or withdrawal at each junction, monthly evaporation, and monthly precipitation. Evaporation and precipitation rates are assumed to be uniform over the entire system; however if rates vary significantly over the system it may be desirable to divide the system into sub-areas and apply different rates to each. Such a refinement would require certain programming changes and would increase input requirements considerably. For most systems mean evaporation and precipitation rates computed from available records from all pertinent gauging stations in the basin would suffice.

Additional input requirements include the head (water surface elevation) at each junction and the channel numbers (up to five) of the channels entering each junction.

Normally the basic input deck for DATAP is the deck resulting from a previous hydraulic solution in which the solution reached steady state. The final junction heads from such a run are thus used as the initial heads in the deck prepared in DATAP. The surface areas and the numbers of all channels entering each junction are also read from that deck. The values for the net inflow or withdrawal (QIN) at each junction are also read from the deck but they will not normally be appropriate for the current run and are therefore reinitialized to zero immediately after they are read. For those junctions where zero is not the desired value for QIN the appropriate value is specified on a separate input card.

Output from DATAP includes a listing of the values for evaporation, precipitation, and the specified inflow or withdrawal. Two decks are punched--one has only the junction numbers and the values of QIN which were specified at each junction (not including evaporation and precipitation), and the other is in the appropriate format for input to the hydraulic program DYNHYD. The initial deck can be used as the basis of the required input deck for the quality program, requiring only the initial concentrations and the specified waste water discharge concentrations for each constituent considered.

## Description and Format of Program Inputs (DATAP)

| Card | Columns | Name | Description |
|---|---|---|---|
| 1 | 1-80 | ALPHA(I) | Alphanumeric identifier which is printed as first line of heading for output (I=1,20 with A4 format). |
| 2 | 1-80 | ALPHA(I) | Alphanumeric identifier which is printed as second line of heading for output (I=21,40 with A4 format). |
| 3 | 1-5R | NJ | Total number of junctions in system. |
|  | 6-10R | MONTH | The number of the month being considered, e.g., 7 for July. |
| *4 | 1-5R | J | Junction number. Read as dummy variable JJ to check card sequence. |
|  | 6-15R. | Y(J) | The head at junction J, in feet. Should be equal to the desired starting head at junction J for the planned hydraulic solution. |
|  | 16-25R. | ASUR(J) | The surface area of junction J, in square feet. |
|  | 26-35R. | QIN(J) | The inflow or withdrawal at junction J, in cfs. Read as dummy variable at this point. |
|  | 36-40R | NCHAN(J,1) | Channel number of one of the channels entering junction J. |
|  | 41-45R | NCHAN(J,2) | Channel number of a second channel entering junction J. |
|  | . . . . | . . . . | . . . . |
|  | 56-60R | NCHAN(J,5) | Channel number of a fifth channel entering junction J. |
| 5 | 1-5R | EVAP | Evaporation, in inches. |
|  | 6-10R | PRECIP | Precipitation, in inches. |

| Card | Column | Name | Description |
|---|---|---|---|
| 6 | 1-5R | NJREAD | The number of junctions for which it is desired to specify a hydraulic input (other than precipitation or evaporation). |
| *7 | 1-5R | J | Number of a junction at which a hydraulic input is to be specified. |
|  | 6-15R. | QIN(J) | The hydraulic input specified at junction J. QIN(J) is negative for a discharge and positive for a withdrawal. |
|  | .... | .... | .... |
|  | .... | .... | Card 7 is repeated as necessary to specify all hydraulic inputs. |

ILLUSTRATIVE EXAMPLE

Following the program listings in the Appendix are partial output listings which resulted from execution of each program. Also following the listings of the two main programs (DYNHYD and DYNQUA) are listings of job control language (JCL) which was utilized for the sequence of runs. To facilitate interpretation of the output this discussion presents a brief description of the sample problem and the required inputs. This discussion should supplement the previous discussions on program input and output.

The illustrative problem utilized the San Diego Bay network which consists of 112 nodes (junctions) with 170 connecting links (channels). The hypothetical problem presented is the simulation of the dynamic steady state distribution of conservative and non-conservative constituents from a point source. Four different constituents are considered, 1) a conservative tracer, 2) a non-conservative tracer, 3) a waste load with an associated biochemical oxygen demand (BOD), and 4) dissolved oxygen (DO), which is linked to constituent 3.

A mean annual tidal condition was selected for the simulation. The tidal coefficients required to specify the desired tide in the hydraulic program were determined by program REGAN. Page 241 of the Appendix is a partial list of the required inputs to REGAN. As can be noted the tidal period associated with the desired tide was adjusted to the nearest half-hour (25.0 hours) for convenience. The tidal elevations (with respect to the datum selected for the model simulation) were specified for each half-hour over the 25.0 hour tidal period

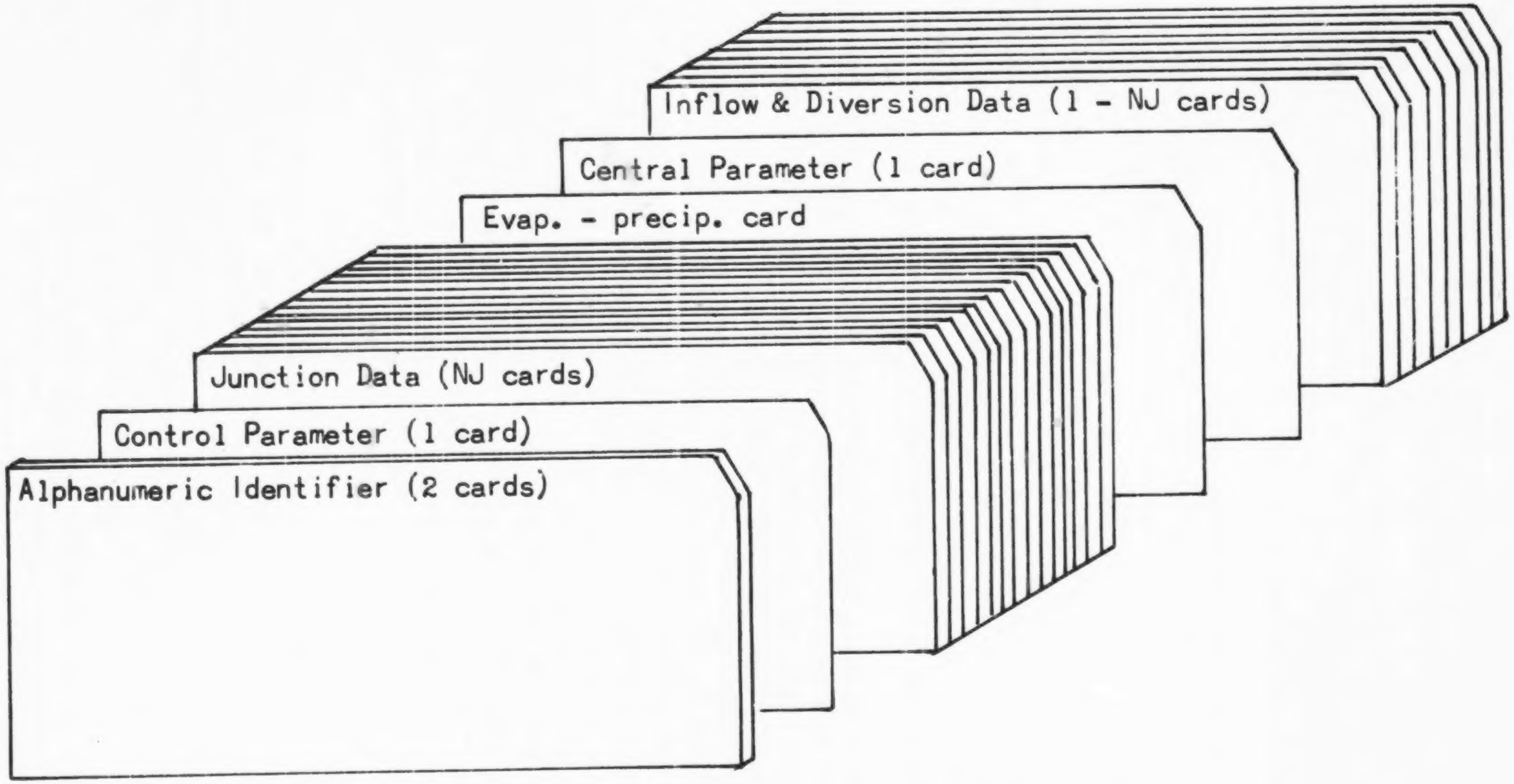

Inflow & Diversion Data (1 - NJ cards)
Central Parameter (1 card)
Evap. - precip. card
Junction Data (NJ cards)
Control Parameter (1 card)
Alphanumeric Identifier (2 cards)

FIGURE 50. SAMPLE DATA DECK MAKEUP - PROGRAM DATAP

(51 points). These values were determined from a graphical plot of the desired tide similar to those presented on page 36. The number of terms in the regression equation was specified as seven.

Output from REGAN (page 242) includes the seven coefficients (which later became input to program DYNHYD) along with a comparison of the tidal elevations computed by the regression coefficients with those specified for each half-hour over the tidal cycle (listed as observed).

The data preparation program DATAP was used to facilitate preparation of the input deck for program DYNHYD. Output from DATAP is listed on pages 246 through 248. The program computes evaporation (or precipitation) from each junction in the network based on the total evaporation (or precipitation) specified for the month. In this example evaporation totaling 4.8 inches for the month of September was specified. The program combines the evaporation withdrawal rate with any other withdrawal or accretion specified (as listed under QIN on pages 246 and 247). This net accretion or depletion is punched in the appropriate format for direct input to program DYNHYD as listed on page 248.

Output from program DYNHYD is presented on pages 194 through 203. For this example the hydraulic simulation was limited to exactly one full tidal cycle. For the specified time step of 50 seconds (DELT = 50.0) this requires 1800 cycles (NCYC = 1800) to complete the full 25-hour tidal cycle. Output was specified at hourly intervals which is equivalent to 72 time steps (NPRT = 72). The printout was to begin at cylcle 72 (IPRT = 72). Computation began at the beginning of the tidal cycle (TZERO = 0.0) which was arbitrarily assigned through the inputs to the regression program REGAN. Because the hydraulic extract subroutine HYDEX requires the computed hydraulic parameters to be stored on unit 10 for each time step over a complete tidal cycle it was necessary that the initial conditions (corresponding to time 0.0 hours) be stored on unit 10 in addition to the results of all 1800 cycles. Thus the binary tape (unit 10) was written from cycle 0 to cycle 1800 as indicated on page 194 (IWRITE = 0). Restart capability after 900 cycles was specified (KPNCHI = 900).

Output from subroutine HYDEX is presented on pages 201 through 203. The desired time step for the quality simulation was one-half hour; therefore the hydraulic parameters were summarized each 36 cycles (NODYN = 36) beginning at cycle 0. The hydraulic cycle associated with the start of each half-hour time period for input to the quality program is listed on page 203.

Output from program DYNQUA is presented on pages 220 through 238. The quality simulation was started at the point on the tidal cycle corresponding to time 0.0 hours in the hydraulic run (NRSTRT = 0). For a simulation of this type wherein the steady state distribution is desired the starting point on the tidal cycle can be arbitrary. For other runs, such as simulation of prototype quality conditions for specific historic periods it may be desirable or even necesssary to begin the simulation at a specific tidal phase. Under such circumstances the quality simulation can begin at any one of the hydraulic cycles which marks the beginning of each quality time step as listed in the output from subroutine HYDEX on page 203. The duration of the quality run was specified as 600 cycles (NQCYC = 600) and, since the run was not a continuation of a previous run, the initial cycle was specified as unity (INQCYC = 1). The 600 quality time steps (one-half hour each) are equivalent to 12 full tidal cycles (12 days and 12 hours). Output was specified at two hour intervals (NPRT = 4) beginning at cycle 50 (IPRT = 50). A quality summary was also specified for the tidal cycle beginning at time step 50 (IWRITE = 50).

For this demonstration run the input deck was prepared with initial junction concentrations equal to 1.0 mg/l for constituent number one rather than the desired 0.5 mg/l at all junctions. The initial concentrations were adjusted to 0.5 mg/l by applying a 0.5 multiplication factor to each junction as indicated on page 222. The initial concentrations listed on page 223 for each junction are the adjusted concentrations.

The point source for tracer and BOD release was specified at junction 52. An arbitrary discharge was specified (18.8 cfs) along with tracer (1190 mg/l), BOD (300 mg/l), and DO (2.0 mg/l) concentrations as indicated on page 223. In addition to the 0.5 mg/l initial concentrations for the first two constituents (both tracer) the initial BOD and DO concentrations were specified as 2.0 and 5.0 mg/l (constituents 3 and 4 respectively).

Another model feature utilized in this example problem was the waste water return factors for selected junctions. As can be noted on page 223 there was a significant diversion (646 cfs) at junction 93 which was cooling water for a power plant. This diversion was returned undiminished in quantity at junction 96. Any constituent diverted with the cooling water should thus be returned undiminshed in quantity (except for decay which would normally be negligible because of the short detention time in the cooling system). This return is accomplished in the model by pairing junction 96 with junction 93 and specifying a return coefficient of 1.00 for each constituent as indicated on page 225 . Two other junctions were also paired (97 and 98) to satisfy program logic; however those junctions have no effect on the solution because neither had a diversion or a return flow assigned.

The effect of the point discharge at junction 52 is evident in the output on pages 226 through 238. The predicted maximum tracer and BOD concentrations occur at the release point (junction 52) while the minimum DO concentration (maximum sag below saturation) occurs nearby.

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# APPENDIX

## PROGRAM LISTINGS AND SAMPLE OUTPUT

PROGRAM DYNHYD

```
C               FEDERAL WATER QUALITY ADMINISTRATION
C             DYNAMIC FLOW IN A TWO-DIMENSIONAL SYSTEM
C                         EXPLICIT SOLUTION

C***********************************************************************
C
C         THE PROGRAM LOGIC IN THIS DECK WAS DEVELOPED FOR THE NETWORKS
C         REPRESENTING THE SAN FRANCISCO BAY-DELTA AND SAN DIEGO BAY
C         SYSTEMS WHEREIN A SINGLE TIDAL CONDITION IS SPECIFIED SIMUL-
C         TANEOUSLY AT TWO NODES(NUMBERED 1 AND 2) AT THE SEAWARD BOUNDARY.
C         APPLICATION TO OTHER SYSTEMS MAY REQUIRE PROGRAM MODIFICATION.
C
C***********************************************************************

      DIMENSION ALPHA(80),Y(840),YT(840),AREAS(840),QIN(840),
     * NCHAN(840,5),CLEN(1300),B(1300),AREA(1300),AREAT(1300),
     * CN(1300),V(1300),VT(1300),Q(1300),R(1300),AK(1300),A( 7),
     * NJUNC(1300,2),JPRT(50)
      COMMON ALPHA,Y,YT,AREA,Q,AREAS,QIN,V,B,CLEN,R,CN,DELT,
     *    NCHAN,NJUNC,JPRT,NJ,NC,NCYC,NPRT,NOPRT,PERIOD,NCYCC
      REWIND 10
      REWIND 3

C********************************************************************
C                     READ, PRINT, AND CHECK DATA
C********************************************************************

C**** GENERAL CONTROL DATA

      READ(5,100)(ALPHA(I),I=1,40)
  100 FORMAT(20A4)
      READ(5,105)NJ,NC,NCYC,NPRT,NOPRT,DELT,TZERO,NETFLW
  105 FORMAT (5I5,2F10.0,I5)
      WRITE(6,110)(ALPHA(I),I=1,40)
  110 FORMAT (1H1///
     *  1H 20A4,10X,37H FEDERAL WATER QUALITY ADMINISTRATION/
     *  1H 20A4,10X,41H DYNAMIC FLOW IN A TWO-DIMENSIONAL SYSTEM////)
      READ(5,530) IPRT,IWRTE,KPNCHI
  530 FORMAT(3I5)
      WRITE(6,115) NJ,NC,NCYC,NPRT,DELT,TZERO,IWRTE,NCYC,KPNCHI,IPRT
  115 FORMAT(132H JUNCTIONS   CHANNELS   CYCLES   OUTPUT INTERVAL   TIME
     * INTERVAL   INITIAL TIME   WRITE BINARY TAPE   RESTART INTERVAL
     *START PRINT//
     * 1H I6,3I11,7H CYCLES,F11.0,5H SEC.,F12.3,14H HRS.  CYCLES I4,4H T
     *O I4,I8,19H CYCLES       CYCLE I4////)

C**** JUNCTION DATA

      DO 119 J=1,NJ
      READ(5,120) JJ,Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5)
  120 FORMAT(I5,3F10.0,5I5)
      YT(J) = Y(J)
      IF(JJ-J)116,119,116
  116 WRITE(6,117) JJ,J
  117 FORMAT(40HOJUNCTION DATA CARD OUT OF SEQUENCE. JJ= I4,4H,J= I4)
      CALL EXIT
  119 CONTINUE
```

```
      WRITE(6,124)
  124 FORMAT (1H ,25X,21H**  JUNCTION DATA  **///)
  121 WRITE(6,125)(J,Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5),J=1,NJ)
  125 FORMAT (86H JUNCTION   INITIAL HEAD   SURFACE AREA   INPUT-OUTPUT
     *     CHANNELS ENTERING JUNCTION//(1H ,I6,F15.4,F17.0,F11.2,I12,
     *     4I6))

C**** CHANNEL DATA

      DO 129 N=1,NC
      READ(5,130) NN,CLEN(N),B(N),AREA(N),R(N),CN(N),V(N),
     *(NJUNC(N,K),K=1,2)
  130 FORMAT( I5,2F8.0,F9.0,F7.0,2F8.0,2I5)
      R(N) = AREA(N) / B(N)
      IF(NN-N)126,129,126
  126 WRITE(6,127) NN,N
  127 FORMAT(39H0CHANNEL DATA CARD OUT OF SEQUENCE. NN= I4,4H,N= I4)
      CALL EXIT
  129 CONTINUE
      WRITE(6,128)
  128 FORMAT (1H1///
     *         1H ,25X,20H**  CHANNEL DATA  **///)
  131 WRITE(6,135)(N,CLEN(N),B(N),AREA(N),CN(N),V(N),R(N),
     *(NJUNC(N,K),K=1,2),N=1,NC)
  135 FORMAT( 97H CHANNEL   LENGTH   WIDTH     AREA    MANNING   VELOCIT
     *Y   HYD RADIUS             JUNCTIONS AT ENDS//
     *(1H I5,F11.0,F8.0,F10.1,F9.3,F10.5,F13.1,      I23,I6))

C**** DATA FOR PRINT LIST

      READ(5,137)(JPRT(I),I=1,NOPRT)
  137 FORMAT(14I5)

C**** DATA FOR BOUNDARY CONDITIONS

      READ(5,137)NK
      READ(5,177)PERIOD,(A(I),I=1,NK)
  177 FORMAT(8F10.0)
      WRITE(6,179)PERIOD,A(1)
  179 FORMAT(1H1///40H **  SPECIFIED TIDAL CHARACTERISTICS  **//
     *  16H TIDAL PERIOD = F5.2,6H HOURS/
     *  19H MEAN TIDE LEVEL = F10.6,5H FEET/
     *  74H HARMONIC    COEFFICIENTS FOR SINE TERMS  *  COEFFICIENTS FOR
     * COSINE TERMS/)
      NS = NK/2 + 1
      DO 449 I=2,NS
      K=I-1
      WRITE(6,448)K,A(I),A(NS+I-1)
  448 FORMAT(1H I2,4H*W*T,F20.6,15X,F17.6)
  449 CONTINUE
      NS = NS - 1

C**** COMPATIBILITY CHECK

      NEXIT = 0
      DO 150 N=1,NC
      DO 150 I=1,2
      J=NJUNC(N,I)
      DO 140 K=1,5
      IF(N-NCHAN(J,K))140,150,140
  140 CONTINUE
      NEXIT=NEXIT+1
      WRITE(6,145) N,J
  145 FORMAT(30HOCOMPATIBILITY CHECK. CHANNEL I4,11H, JUNCTION I4)

  150 CONTINUE
      DO 170 J=1,NJ
      DO 165 K=1,5
      IF(NCHAN(J,K))170,170,155
  155 N=NCHAN(J,K)
      DO 160 I=1,2
      IF( J-NJUNC(N,I))160,165,160
  160 CONTINUE
      NEXIT=NEXIT+1
      WRITE(6,145) N,J
  165 CONTINUE
  170 CONTINUE
      IF(NEXIT)176,176,175
  175 CALL EXIT
  176 CONTINUE

C**** STORE CONTROL AND SYSTEM DATA ON TAPE 10

      WRITE(10)      (ALPHA(I),I=1,40),NJ,NC,DELT,(CN(N),R(N),B(N),
     *    CLEN(N),N=1,NC)
      WRITE(10)      (Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5),J=1,NJ),
     *     (AREA(N),V(N),(NJUNC(N,I),I=1,2),N=1,NC)


C***********************************************************************
C                                 INITIALIZATION
C***********************************************************************

      DELT2  = DELT/2.0
      TZERO  = TZERO*3600.
      PERIOD = PERIOD*3600.
      W      = 6.2832/PERIOD
      KWRITE = KPNCHI
      G = 32.1739

C*****CHANNEL CONSTANTS

      DO 190 N=1,NC
      AK(N) = G * (CN(N)**2/2.208196)
      IF(NJUNC(N,1)-NJUNC(N,2))190,190,185
  185 KEEP=NJUNC(N,1)
      NJUNC(N,1)=NJUNC(N,2)
      NJUNC(N,2)=KEEP
  190 CONTINUE


C***********************************************************************
C                                 MAIN LOOP
C***********************************************************************


      IF(IWRTE)298,298,301
  298 DO 300 N=1,NC
      Q(N) = AREA(N) * V(N)
  300 CONTINUE
      WRITE(10)      IWRTE,(Y(J),J=1,NJ),(V(N),Q(N),N=1,NC)
  301 T = TZERO
      DO 285 ICYC=1,NCYC
      NCYCC = ICYC
      T2 = T + DELT2
      T  = T + DELT

C*********HALF-STEP VELOCITIES

      DO 204 N=1,NC
      NL=NJUNC(N,1)
      NH=NJUNC(N,2)
      R(N) = AREA(N) / B(N)
      AKT = AK(N) / (R(N)**1.333333)
      DVDX = (1.0/R(N))*(((Y(NH)-YT(NH)+Y(NL)-YT(NL))/DELT)+
     *  (V(N)/CLEN(N))*(Y(NH)-Y(NL)))
      VT(N)=V(N)+DELT2*((V(N)*DVDX)          -AKT  *V(N)*ABS (V(N))
     *  -(G/CLEN(N))*(Y(NH)-Y(NL)))
  204 Q(N)=VT(N)*AREA(N)

C*********HALF-STEP HEADS

      YT(1) = A(1)
      DO 450 I=1,NS
      FI = FLOAT(I)
      YT(1) = YT(1) + A(I+1)*SIN(FI*W*T2)+A(NS+1+I)*COS(FI*W*T2)
  450 CONTINUE
      YT(2) = YT(1)
      DO 225 J =3,NJ
      SUMQ=QIN(J)
      DO 220 K=1,5
      IF(NCHAN(J,K))225,225,205
  205 N=NCHAN(J,K)
      IF(J-NJUNC(N,1))215,210,215
  210 SUMQ=SUMQ+Q(N)
      GO TO 220
  215 SUMQ=SUMQ-Q(N)
  220 CONTINUE
  225 YT(J) = Y(J) - ((DELT/AREAS(J))*0.5)*SUMQ

C*********HALF-STEP             AREAS --- FULL-STEP VELOCITIES

      DO 230 N=1,NC
      NL=NJUNC(N,1)
      NH=NJUNC(N,2)
      AREAT(N)=AREA(N)+0.5*B(N)*(YT(NH)-Y(NH)+YT(NL)-Y(NL))
      R(N) = AREAT(N) / B(N)
      AKT2 = AK(N) / (R(N)**1.333333)
      DVDX = (1.0/R(N))*(((YT(NH)-Y(NH)+YT(NL)-Y(NL))/DELT) +
     *  (VT(N)/CLEN(N)) * (YT(NH)-YT(NL)))
      V(N)=V(N)+DELT*((VT(N)*DVDX)          -AKT2 *VT(N)*ABS (VT(N))
     *  -(G/CLEN(N)) * (YT(NH)-YT(NL)))
  230 Q(N)=V(N)*AREAT(N)

C*********FULL-STEP HEADS

      Y (1) = A(1)
      DO 451 I=1,NS
      FI = FLOAT(I)
      Y (1) = Y (1) + A(I+1)*SIN(FI*W*T )+A(NS+1+I)*COS(FI*W*T )
  451 CONTINUE
      Y(2) = Y(1)
      DO 255 J =3,NJ
      SUMQ=QIN(J)
      DO 250 K=1,5
      IF(NCHAN(J,K))255,255,235
  235 N=NCHAN(J,K)
      IF(J-NJUNC(N,1))245,240,245
  240 SUMQ=SUMQ+Q(N)
      GO TO 250
  245 SUMQ=SUMQ-Q(N)
  250 CONTINUE
  255 Y(J) = Y(J) - (DELT/AREAS(J))*SUMQ

C*********FULL-STEP WIDTHS AND AREAS

      DO 256 N=1,NC
      NL=NJUNC(N,1)
      NH=NJUNC(N,2)
  256 AREA(N) = AREAT(N)+0.5*B(N)*(Y(NH)-YT(NH)+Y(NL)-YT(NL))

C**** WRITE BINARY TAPE FOR WATER QUALITY PROGRAM

      IF(ICYC-IWRTE)259,252,252
  252 WRITE(10)      ICYC,(Y(J),J=1,NJ),(V(N),Q(N),N=1,NC)


C*********************************************************************
C                             HYDRAULIC OUTPUT
C*********************************************************************


  259 IF(ICYC - IPRT)260,261,260
  260 IF(ICYC - NCYC)263,261,263
  261 IPRT=IPRT+NPRT
  262 CONTINUE

C**** SELECTIVE PRINT ROUTINE

      TIME = T/3600.0
      WRITE(6,302) ICYC,TIME
  302 FORMAT(1H1///
     *        27H SYSTEM STATUS AFTER CYCLE I4,F12.2,6H HOURS//
     *        54H JUNCTION       HEAD      CHANNEL       VELOCITY        FLOW/
     *        54H  NUMBER        (FT)       NUMBER         (FPS)       (CFS))
      DO 340 I=1,NOPRT
      J=JPRT(I)
      WRITE(6,305) J,Y(J)
  305 FORMAT(1H0I5,F13.4)
      DO 335 K=1,5
      IF(NCHAN(J,K))335,335,310
  310 N=NCHAN(J,K)
      IF(J-NJUNC(N,1))320,315,320
  315 VEL=V(N)
      FLOW=Q(N)
      GO TO 325
  320 VEL=-V(N)
      FLOW=-Q(N)
  325 WRITE(6,330) N,VEL,FLOW
  330 FORMAT (1H I28,F14.5,F12.1)
  335 CONTINUE
  340 CONTINUE

C**** CHECK VELOCITIES AND RECYCLE

  263 DO 275 N=1,NC
      IF(ABS (V(N))- 20.0)275,265,265
  265 WRITE(6,270) ICYC,N
  270 FORMAT(34HOVELOCITY EXCEEDS 20 FPS IN CYCLE I3,10H, CHANNEL I3,
     *23H, EXECUTION TERMINATED.)
      WRITE(6,271)(J,Y(J),YT(J),AREA(J),Q(J),J=1,NJ)
      L=NJ+1
      WRITE (6,272)(J,AREA(J),Q(J),J=L,NC)
  271 FORMAT  (52H   NO.        Y                YT          AREA          Q//
     *      (I5,F13.6,F13.6,F15.1,F14.2))
  272 FORMAT(I5,26X,F15.1,F14.2)
      CALL EXIT
  275 CONTINUE

C***** WRITE TAPE FOR RESTARTING

  279 IF(ICYC - NCYC)278,405,405
  278 IF(ICYC - KWRITE)285,277,277
  277 KWRITE = KWRITE + KPNCHI
      WRITE(3) ICYC,(Y(J),YT(J),J=1,NJ),(V(N),AREA(N),N=1,NC)
      REWIND 3
      GO TO 415

C***** PUNCH RESTART DECK

  405 WRITE(8,406)(J,Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5),J=1,NJ)
  406 FORMAT (I5,F10.4,F10.0,F10.2,5I5)
  413 WRITE(8,414)(N,CLEN(N),B(N),AREA(N),R(N),CN(N),V(N),
     *  (NJUNC(N,K),K=1,2),N=1,NC)
  414 FORMAT(I5,2F8.0,F9.1,F7.2,F8.3,F8.5,2I5)
  415 TZERO2 = T / PERIOD
      KTZERO = TZERO2
      TZERO2 = (T/3600.) - FLOAT (KTZERO) *(PERIOD/3600.)
      WRITE(6,281) ICYC,TZERO2
  281 FORMAT(1H1///48H RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE I4
     *,26H    TZERO FOR RESTARTING = F10.7)
  285 CONTINUE

C***** PRINT RESTART DATA

C*     JUNCTION DATA

  400 WRITE(6,402)
  402 FORMAT (1H1///
     *          32H  JUNCTION DATA FOR RESTART DECK///)
      WRITE(6,404) (J,Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5),J=1,NJ)
  404 FORMAT (86H JUNCTION   INITIAL HEAD   SURFACE AREA   INPUT-OUTPUT
     *      CHANNELS ENTERING JUNCTION//(1H ,I6,F15.4,F17.0,F11.2,I12,
     *       4I6))

C*     CHANNEL DATA

  409 WRITE(6,410)
  410 FORMAT (1H1///
     *          31H  CHANNEL DATA FOR RESTART DECK///)
      WRITE(6,412)              (N,CLEN(N),B(N),AREA(N),CN(N),V(N),R(N),
     *(NJUNC(N,K),K=1,2),N=1,NC)
  412 FORMAT( 97H CHANNEL   LENGTH   WIDTH     AREA    MANNING   VELOCIT
     *Y   HYD RADIUS             JUNCTIONS AT ENDS//
     *(1H I5,F11.0,F8.0,F10.1,F9.3,F10.5,F13.2,       I23,I6))
      WRITE(6,299) IWRTE,NCYCC
  299 FORMAT(32HOTAPE 10 WAS WRITTEN FROM CYCLF I6,10H TO CYCLE I6//)
```

```
C**** EXIT

      WRITE(6,422) NCYCC
  422 FORMAT(42H0END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. I4,8H CYCLES.)
  424 IF(NETFLW)426,428,426
  426 CALL HYDEX
  428 CALL EXIT
      END
```

```
      SUBROUTINE HYDEX

C                    FEDERAL WATER QUALITY ADMINISTRATION
C                                NET FLOW PROGRAM

      DIMENSION YAVE(840)
      DIMENSION VMIN(1300),VMAX(1300),ARMIN(1300),ARMAX(1300),
     * QEXMIN(1300),QEXMAX(1300),YMIN(840),YMAX(840),RANGE(840),
     * ARAVE(1300),NMIN(800),NMAX(800)
      DIMENSION ALPHA(80),Y(840),AREAS(840),QIN(840),NCHAN(840,5),
     * V(1300),Q(1300),AREA(1300),B(1300),CLEN(1300),R(1300),
     * CN(1300),NJUNC(1300,2),JPRT(50),YNEW(840),QNET(1300),
     *  QEXT(1300),VEXT(1300),YT(840)
      COMMON ALPHA,Y,YT,AREA,Q,AREAS,QIN,V,B,CLEN,R,CN,DELT,
     *    NCHAN,NJUNC,JPRT,NJ,NC,NCYC,NPRT,NOPRT,PERIOD,NCYCC
      REWIND 10
      REWIND 3
      DO 78 N=1,NC
      ARAVE(N) = 0.0
   78 CONTINUE

C**** READ INDEPENDENT CONTROL DATA

      READ(5,103)(ALPHA(I),I=41,80)
  103 FORMAT(20A4)
      READ(5,80) NODYN
   80 FORMAT(5I5)

C**** READ SYSTEM INFORMATION FROM DYNAMIC FLOW PROGRAM

      READ(10)      (ALPHA(I),I=1,40),NJ,NC,DELT,(CN(N),R(N),B(N),
     *    CLEN(N),N=1,NC)
      READ(10)      (Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5),J=1,NJ),
     *     (AREA(N),V(N),(NJUNC(N,I),I=1,2),N=1,NC)
      NSTOP = NCYCC
      NSTART = NCYCC - (PERIOD / DELT)
      WRITE(6,105)(ALPHA(I),I=1,80)
  105 FORMAT (1H1///
     *  1H 20A4,10X,37H FEDERAL WATER QUALITY ADMINISTRATION/
     *  1H 20A4,10X,32H NET FLOWS AND HYDRAULIC SUMMARY/
     *         1H 20A4/1H 20A4////)
      DELTQ=DELT*FLOAT (NODYN)/3600.0
      WRITE(6,351) NSTART,NSTOP,DELT,NODYN,DELTQ
  351 FORMAT(88H ******** FROM HYDRAULICS PROGRAM ********     HYDRAULIC
     * CYCLES PER      TIME INTERVAL IN/
     *87H START CYCLE   STOP CYCLE    TIME INTERVAL         QUALITY CYCLE
     *         QUALITY PROGRAM//
     *1H I7,I14,F11.0,9H  SECONDS,10X,I6,12X,F9.2,7H  HOURS/////)

C**** EXTRACT HYDRAULICS TAPE AND COMPUTE NET FLOWS

  200 JRITE = NSTART
  202 READ(10) ICYCTF,(YNEW(J),J=1,NJ),(V(N),Q(N),N=1,NC)
  203 IF(ICYCTF - NSTART)202,204,208
  204 DO 206 N=1,NC
      QNET(N) = 0.5*Q(N)
      QEXT(N) = 0.5*Q(N)
      VEXT(N) = 0.5*V(N)
      VMIN(N) = V(N)
      VMAX(N) = V(N)
  206 CONTINUE
      KFLAG = 0
      KFLAG2 = 0
      DO 207 J=1,NJ
      YAVE(J) = 0.0
      YMIN(J) = YNEW(J)
      NMIN(J) = ICYCTF
      YMAX(J) = YNEW(J)
      NMAX(J) = ICYCTF
  207 CONTINUE
      GO TO 218
  208 KFLAG = KFLAG + 1
      DO 154 N=1,NC
      IF(V(N))152,150,152
  150 NL = NJUNC(N,1)
      NH = NJUNC(N,2)
      AREA(N) = AREA(N) +((B(N)/2.) * (YNEW(NH)-Y(NH) + YNEW(NL)-Y(NL)))
      ARAVE(N) = ARAVE(N) + AREA(N)
      GO TO 154
  152 AREA(N) = Q(N) / V(N)
      ARAVE(N) = ARAVE(N) + AREA(N)
  154 CONTINUE
      IF(KFLAG - 1)157,155,157
  155 DO 156 N=1,NC
      ARMIN(N) = AREA(N)
      ARMAX(N) = AREA(N)
  156 CONTINUE
  157 CONTINUE
      DO 210 N=1,NC
      QNET(N) = QNET(N) + Q(N)
      QEXT(N) = QEXT(N) + Q(N)
      VEXT(N) = VEXT(N) + V(N)
      IF(V(N) - VMAX(N))160,158,158
  158 VMAX(N) = V(N)
      GO TO 164
  160 IF(V(N) - VMIN(N))162,162,164
  162 VMIN(N) = V(N)
  164 CONTINUE
      IF(AREA(N) - ARMAX(N))168,166,166
  166 ARMAX(N) = AREA(N)
      GO TO 172
  168 IF(AREA(N) - ARMIN(N))170,170,172
  170 ARMIN(N) = AREA(N)
  172 CONTINUE
  210 CONTINUE
```

```
      DO 180 J=1,NJ
      IF(YNEW(J) - YMAX(J))176,174,174
  174 YMAX(J) = YNEW(J)
      NMAX(J) = ICYCTF
      GO TO 179
  176 IF(YNEW(J) - YMIN(J))178,178,179
  178 YMIN(J) = YNEW(J)
      NMIN(J) = ICYCTF
  179 CONTINUE
  180 CONTINUE
      DO 211 J=1,NJ
      Y(J) = YNEW(J)
      YAVE(J) = YAVE(J) + YNEW(J)
  211 CONTINUE
      IF(ICYCTF - JRITE)213,212,213
  213 GO TO 202
  212 KFLAG2 = KFLAG2 + 1
      DO 214 N=1,NC
      QEXT(N) = QEXT(N) - 0.5*Q(N)
      QEXT(N) = QEXT(N)/FLOAT (NODYN)
      VEXT(N) = VEXT(N) - 0.5*V(N)
      VEXT(N) = VEXT(N)/FLOAT (NODYN)
  214 CONTINUE
      IF(KFLAG2 - 1)183,215,183
  215 DO 181 N=1,NC
      QEXMIN(N) = QEXT(N)
      QEXMAX(N) = QEXT(N)
  181 CONTINUE
      GO TO 188
  183 DO 187 N=1,NC
      IF(QEXT(N) - QEXMAX(N))184,182,182
  182 QEXMAX(N) = QEXT(N)
      GO TO 187
  184 IF(QEXT(N) - QEXMIN(N))186,186,187
  186 QEXMIN(N) = QEXT(N)
  187 CONTINUE
  188 CONTINUE
      WRITE(3) (QEXT(N),VEXT(N),N=1,NC)
      DO 216 N=1,NC
      QEXT(N) = 0.5*Q(N)
      VEXT(N) = 0.5*V(N)
  216 CONTINUE
      IF(ICYCTF-NSTOP)218,220,220
  218 WRITE(3) ICYCTF,(YNEW(J),J=1,NJ)
      JRITE = JRITE + NODYN
      GO TO 202
  220 DO 222 N=1,NC
      QNET(N) = QNET(N) - 0.5*Q(N)
      QNET(N) = QNET(N)/FLOAT (NSTOP-NSTART)
      ARAVE(N) = ARAVE(N) /FLOAT (NSTOP-NSTART)
      R(N) = ARAVE(N) / B(N)
  222 CONTINUE

      DO 260 J=1,NJ
      RANGE(J) = YMAX(J) - YMIN(J)
      YAVE(J) = YAVE(J) / FLOAT (NSTOP - NSTART)
  260 CONTINUE

      REWIND 10
      WRITE(3)(QNET(N),N=1,NC)
      WRITE(3)(ALPHA(I),I=1,40),NJ,NC,DELT,(CN(N),R(N),B(N),
     *    CLEN(N),N=1,NC)
```

```
      WRITE(3)   (YAVE(J),AREAS(J),OIN(J),(NCHAN(J,K),K=1,5),J=1,NJ),
     *       (ARAVE(N), (NJUNC(N,I),I=1,2),N=1,NC)
      WRITE(6,224)(N,ONET(N),QEXMIN(N),QEXMAX(N),VMIN(N),
     *  VMAX(N),ARMIN(N),ARMAX(N),ARAVE(N),N=1,NC)
  224 FORMAT(119H                          * * * * *  FLOW  * * * * *
     *    * *   VELOCITY   * *       * * *  CROSS-SECTIONAL AREA  * * */
     *        118H CHANNEL     NET FLOW           MIN.             MAX.
     *      MIN.           MAX.            MIN.           MAX.          AVE./
     *        119H NUMBER          (CFS)              (CFS)              (CFS)
     *     (FPS)           (FPS)           (SQ. FT)     (SQ. FT)    (SO. FT)//
     *  (1H I5,F15.2,2F16.2,2F13.3,F16.1,F13.1,F12.1))
      REWIND 3
      WRITE(6,262)(J,YMIN(J),NMIN(J),YMAX(J),NMAX(J),YAVE(J),RANGE(J),
     *    J=1,NJ)
  262 FORMAT(1H1////
     * 98H JUNCTION    MINIMUM HEAD    OCCURS AT    MAXIMUM HEAD    OCCU
     *RS AT    AVERAGE HEAD    TIDAL RANGE/
     * 94H  NUMBER           (FT)             CYCLE             (FT)           CY
     *CLE             (FT)             (FT)//
     *  (1H I6,F15.2,I13,F16.2,I13,F16.2,F15.2))
C**** CHECK DATA ON BINARY TAPE
      K=(NSTOP-NSTART)/NODYN
      WRITE(6,242)
  242 FORMAT(1H1///
     *        53H **** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****///
     *        49H HYDRAULIC       HEAD AT          *FLOW IN CHANNEL*/
     *        49H   CYCLE     JUNCTION NO.1      NO.1           NO.2//)
      DO 234 I=1,K
      READ(3) ICYCTF,(YNEW(J),J=1,NJ)
      READ(3) (QEXT(N),VEXT(N),N=1,NC)
      WRITE(6,232) ICYCTF, YNEW(1),QEXT(1),QEXT(2)
  232 FORMAT(I7,5X,F10.2,6X,F11.2,F12.2)
  234 CONTINUE
      REWIND 3
      WRITE(6,240)
  240 FORMAT(25H0END OF NET FLOW PROGRAM.)
      RETURN
      END
```

## SAMPLE JOB CONTROL LANGUAGE FOR PROGRAM DYNHYD

```
//I18012F7 JOB (807200,I0902,0015,0014,0350,1,1,,61),'FEIGNER',        X
//             CLASS=B,MSGLEVEL=1
/*SETUP  002033/9R
// EXEC FORTGCLG,TIME=15,REGION.FORT=252K,REGION.GO=252K
//FORT.SYSIN DD *


**********  INSERT SOURCE DECK HERE  **********


/*
//GO.FT03F001 DD UNIT=2400,DCB=(RECFM=VBS,LRECL=504,BLKSIZE=5040),    X
//     DISP=(NEW,KEEP),LABEL=(,,,IN),DSNAME=SDBHX,                     X
//     VOL=SER=002033
//GO.FT10F001 DD UNIT=SYSDK.DCR=(RECFM=VBS,LRECL=504,BLKSIZE=5040),   X
//     DISP=(NEW,DELETE),SPACE=(CYL,(30,30),RLSE),DSN=SDBHY
//GO.SYSIN DD *


**********  INSERT DATA HERE  **********


/*
```

```
SAN DIEGO BAY HYDRAULICS WITH MEAN ANNUAL TIDE(25.0 HOUR PERIOD)                              FEDERAL WATER QUALITY ADMINISTRATION
DEMONSTRATION RUN FOR DOCUMENTATION REPORT            05-27-70                                DYNAMIC FLOW IN A TWO-DIMENSIONAL SYSTEM


JUNCTIONS   CHANNELS   CYCLES   OUTPUT INTERVAL   TIME INTERVAL   INITIAL TIME   WRITE BINARY TAPE   RESTART INTERVAL   START PRINT

   112         170      1800          72 CYCLES        50. SEC.        0.0   HRS.  CYCLES   0 TO 1800     900 CYCLES        CYCLE   72


                         **  JUNCTION DATA  **


JUNCTION    INITIAL HEAD    SURFACE AREA    INPUT-OUTPUT       CHANNELS ENTERING JUNCTION

     1         2.6020         5500000.          0.80             1     2     0     0     0
     2         2.6020         3125000.          0.50             2     0     0     0     0
     3         2.6020        10500000.          1.60             1     3     0     0     0
     4         2.6020        11454545.          1.80             3     4     0     0     0
     5         2.6362         7827273.          1.20             4     5     6     0     0
     6         2.6578         5781818.          0.90             5     8     9     0     0
     7         2.6489         3436363.          0.50             6     7     0     0     0
     8         2.6620         3627273.          0.60             7     9    10     0     0
     9         2.6754         5645455.          0.90             8    11     0     0     0
    10         2.6842         3163636.          0.50            10    13    14     0     0
    11         2.6934         6763636.          1.00            11    12    13     0     0
    12         2.6868         2345454.          0.40            14    15     0     0     0
    13         2.6875         4581818.          0.70            15    16     0     0     0
    14         2.6876         2127273.          0.30            16     0     0     0     0
    15         2.7176         7009091.          1.10            12    17     0     0     0
    16         2.7421         6163636.          1.00            17    18    19    21     0
    17         2.7428         2918182.          0.50            19    20     0     0     0
     .              .                .             .             .     .     .     .     .
     .              .                .             .             .     .     .     .     .
     .              .                .             .             .     .     .     .     .
   101         3.0173         3900000.          0.60           149   151     0     0     0
   102         3.0257          545455.          0.10           152   153     0     0     0
   103         3.0329         1309091.          0.20           153     0     0     0     0
   104         2.8995         1281818.          0.20           154   155   156     0     0
   105         2.9110         1390909.          0.20           156   157     0     0     0
   106         2.9167         1390909.          0.20           158     0     0     0     0
   107         2.9330         2727273.          0.40           159   160     0     0     0
   108         2.9413         2563636.          0.40           160   161   162     0     0
   109         2.9485         2836364.          0.40           162   163   164     0     0
   110         2.9527         2945455.          0.50           164   165     0     0     0
   111        -3.0000         3125000.          0.50           170     0     0     0     0
   112        -3.0000         3125000.          0.50           170     0     0     0     0
```

```
                        **  CHANNEL DATA  **

CHANNEL   LENGTH   WIDTH     AREA    MANNING  VELOCITY   HYD RADIUS          JUNCTIONS AT ENDS

   1       2500.   4400.  143178.0    0.015  -0.01362      32.5                    1     3
   2       2500.   2500.   88334.4    0.015   0.0          35.3                    1     2
   3       2500.   4200.  128258.9    0.015  -0.01492      30.5                    3     4
   4       2500.   1700.   90875.9    0.015  -0.61698      53.5                    4     5
   5       2500.   2400.  106882.4    0.015  -0.40138      44.5                    5     6
   6       2500.   1500.   60946.8    0.015  -0.21437      40.6                    5     7
   7       2500.   1500.   57966.3    0.015  -0.22431      38.6                    7     8
   8       2500.   2350.  107046.5    0.015  -0.32512      45.6                    6     9
   ●         ●       ●         ●        ●         ●          ●                     ●     ●
   ●         ●       ●         ●        ●         ●          ●                     ●     ●
   ●         ●       ●         ●        ●         ●          ●                     ●     ●
 159       2100.   2050.   65441.5    0.015  -0.04254      31.9                   50   107
 160       2500.   1200.   19108.0    0.015  -0.12633      15.9                  107   108
 161       2100.   2400.   83593.9    0.015  -0.01236      34.8                   52   108
 162       2100.   1300.   20711.6    0.015  -0.14923      15.9                  108   109
 163       2100.   1200.   40721.9    0.015   0.02578      33.[illegible]         54   109
 164       2100.   1600.   25503.9    0.015  -0.06425      15.9                  109   110
 165       2100.   1100.   32932.6    0.015   0.03693      29.9                   56   110
 166       1950.   1300.   44126.1    0.015  -0.03365      33.9                   56    58
 167       2100.   1450.   23123.7    0.015  -0.05357      15.9                   58    60
 168       1950.   1800.   57512.6    0.015   0.01527      32.0                   59    60
 169       1650.   1500.   25422.7    0.015  -0.08194      16.9                   57    59
 170       2500.   2500.   75000.0    0.015   0.0          30.0                  111   112




**  SPECIFIED TIDAL CHARACTERISTICS  **

TIDAL PERIOD = 25.00 HOURS
MEAN TIDE LEVEL =    0.067964 FEET
HARMONIC     COEFFICIENTS FOR SINE TERMS  *  COEFFICIENTS FOR COSINE TERMS

 1*W*T           -0.878729                         0.768662
 2*W*T            0.559115                         1.740088
 3*W*T           -0.082364                         0.025251
```

```
SYSTEM STATUS AFTER CYCLE  360        5.00 HOURS

JUNCTION      HEAD      CHANNEL     VELOCITY      FLOW
 NUMBER       (FT)       NUMBER       (FPS)       (CFS)

    1       -1.5814
                            1      -1.05205   -131253.6
                            2       0.0             0.0

    2       -1.5814
                            2       0.0             0.0

    5       -1.6143
                            4       1.50025    125545.7
                            5      -0.95528    -92317.5
                            6      -0.57167    -31193.6

    9       -1.6329
                            8       0.77239     74881.1
                           11      -0.79320    -73418.3

   16       -1.6644
                           17       1.04434    111964.3
                           18      -0.79004    -80046.6
                           19      -0.04226     -1436.5
                           21      -0.42027    -28895.9

   24       -1.6695
                           25       0.04464       363.9

   30       -1.6867
                           32       0.19185     11024.3
                           33       0.51705     31645.1
                           36      -0.60075    -37688.8
                           37      -0.31784     -4059.5

   36       -1.6984
                           39       0.40146     31655.4
                           42       0.26754     11331.1
                           46      -0.21834    -13805.5
                           47      -0.60991    -27666.4

   42       -1.7289
                           53       0.97169     74113.5
                           56      -0.88453    -59005.5
                           57      -0.08775     -4685.5
                           59      -0.59315     -9211.7

   48       -1.7566
                           69       0.85169     64969.4
                           72      -0.77792    -62971.1
                           74      -0.25872     -5088.4
                          157       0.20972      5077.3
                          158      -0.01088      -370.3
```

```
SYSTEM STATUS AFTER CYCLE  864        12.00 HOURS

JUNCTION       HEAD     CHANNEL     VELOCITY       FLOW
 NUMBER        (FT)      NUMBER       (FPS)        (CFS)

    1        0.6878
                             1      0.71947      96904.7
                             2      0.0              0.0

    2        0.6878
                             2      0.0              0.0

    5        0.6975
                             4     -1.05566     -92421.3
                             5      0.65898      67311.1
                             6      0.40538      23520.4

    9        0.7026
                             8     -0.53111     -54367.7
                            11      0.54376      53227.0

   16        0.7104
                            17     -0.72240     -81852.1
                            18      0.52701      56377.4
                            19      0.03040       1119.4
                            21      0.31577      23120.9

    •           •            •         •             •
    •           •            •         •             •
    •           •            •         •             •

   48        0.7278
                            69     -0.54945     -45220.1
                            72      0.49548      43284.7
                            74      0.22295       5349.9
                           157     -0.17187      -4882.5
                           158      0.00736        273.5


RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE  900   TZERO FOR RESTARTING = 12.5000000
```

```
SYSTEM STATUS AFTER CYCLE 1800       25.00 HOURS

JUNCTION       HEAD    CHANNEL      VELOCITY        FLOW
 NUMBER        (FT)     NUMBER        (FPS)         (CFS)

   1         2.6020
                           1        0.02045       2926.1
                           2        0.0              0.0

   2         2.6020
                           2        0.0              0.0

   5         2.6541
                           4       -0.03194      -2900.3
                           5        0.01047       1118.6
                           6        0.02898       1766.6

   9         2.6790
                           8       -0.01429      -1528.9
                          11        0.01479       1514.6

  16         2.7207
                          17       -0.02336      -2767.4
                          18        0.00429        479.2
                          19        0.00052         20.3
                          21        0.02916       2245.6
   •            •          •            •            •
   •            •          •            •            •
   •            •          •            •            •

  48         2.8257
                          69       -0.09257      -8089.4
                          72        0.07610       7060.4
                          74        0.03733       1033.2
                         157       -0.00166        -53.2
                         158        0.00023          9.1



RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE 1800   TZERO FOR RESTARTING =  0.0
```

```
JUNCTION DATA FOR RESTART DECK

JUNCTION   INITIAL HEAD   SURFACE AREA   INPUT-OUTPUT     CHANNELS ENTERING JUNCTION

    1         2.6020        5500000.         0.80          1    2    0    0    0
    2         2.6020        3125000.         0.50          2    0    0    0    0
    3         2.6163       10500000.         1.60          1    3    0    0    0
    4         2.6322       11454545.         1.80          3    4    0    0    0
    5         2.6541        7827273.         1.20          4    5    6    0    0
    6         2.6678        5781818.         0.90          5    8    9    0    0
    7         2.6622        3436363.         0.50          6    7    0    0    0
    8         2.6705        3627273.         0.60          7    9   10    0    0
    9         2.6790        5645455.         0.90          8   11    0    0    0
   10         2.6846        3163636.         0.50         10   13   14    0    0
   11         2.6904        6763636.         1.00         11   12   13    0    0
   12         2.6868        2345454.         0.40         14   15    0    0    0
   13         2.6874        4581818.         0.70         15   16    0    0    0
   14         2.6875        2127273.         0.30         16    0    0    0    0
   15         2.7054        7009091.         1.10         12   17    0    0    0
   16         2.7207        6163636.         1.00         17   18   19   21    0
   17         2.7212        2918182.         0.50         19   20    0    0    0
    •            •              •              •           •    •    •    •    •
    •            •              •              •           •    •    •    •    •
    •            •              •              •           •    •    •    •    •
   89         2.8799        7200000.         1.10        133  134  136  137    0
   90         2.8773        6300000.         1.00        131  134  135  138    0
   91         2.8774        6872727.         1.10        132  135  139    0    0
   92         2.8825        5481818.         0.80        136  140    0    0    0
   93         2.8830        5427273.       646.80        140  141    0    0    0
   94         2.8824        6790909.         1.00        137  141  142  143    0
   95         2.8800        5972727.         0.90        138  139  142  144    0
   96         2.8878        6572727.      -645.00        145  147    0    0    0
   97         2.8852        6272727.         1.00        143  145  146  148    0
   98         2.8837        6245455.         1.00        144  146  149    0    0
   99         2.8878        2645455.         3.00        147  150  152    0    0
  100         2.8865        4118182.         0.60        148  150  151    0    0
  101         2.8853        3900000.         0.60        149  151    0    0    0
  102         2.8900         545455.         0.10        152  153    0    0    0
  103         2.8939        1309091.         0.20        153    0    0    0    0
  104         2.8160        1281818.         0.20        154  155  156    0    0
  105         2.8226        1390909.         0.20        156  157    0    0    0
  106         2.8259        1390909.         0.20        158    0    0    0    0
  107         2.8353        2727273.         0.40        159  160    0    0    0
  108         2.8402        2563636.         0.40        160  161  162    0    0
  109         2.8444        2836364.         0.40        162  163  164    0    0
  110         2.8468        2945455.         0.50        164  165    0    0    0
  111        -3.0137        3125000.         0.50        170    0    0    0    0
  112        -3.0137        3125000.         0.50        170    0    0    0    0
```

```
CHANNEL DATA FOR RESTART DECK

CHANNEL   LENGTH   WIDTH      AREA    MANNING   VELOCITY   HYD RADIUS          JUNCTIONS AT ENDS

   1      2500.    4400.   143103.9    0.015    0.02045      32.52                      1     3
   2      2500.    2500.    88227.6    0.015    0.0          35.29                      1     2
   3      2500.    4200.   128245.1    0.015    0.02274      30.53                      3     4
   4      2500.    1700.    90811.3    0.015    0.03194      53.42                      4     5
   5      2500.    2400.   106809.0    0.015    0.01047      44.50                      5     6
   6      2500.    1500.    60963.7    0.015    0.02898      40.64                      5     7
   7      2500.    1500.    57976.0    0.015    0.03035      38.65                      7     8
   8      2500.    2350.   106955.6    0.015    0.01429      45.51                      6     9
   9      2350.    2200.    91293.1    0.015   -0.00464      41.50                      5     8
  10      2500.    1250.    52073.4    0.015    0.02549      41.66                      8    10
  11      2500.    2300.   102398.8    0.015    0.01479      44.52                      9    11
  12      2500.    2800.   121978.3    0.015    0.02287      43.56                     11    15
  13      2350.    2350.   111688.4    0.015    0.01159      47.53                     10    11
  14      2100.     650.    12122.3    0.015    0.00203      18.65                     10    12
  15      2100.    1650.    34110.1    0.015    0.00053      20.67                     12    13
  16      2100.    2100.    39220.3    0.015    0.00015      18.68                     13    14
  17      2500.    2600.   118475.4    0.015    0.02336      45.57                     15    16
  18      2500.    2400.   111769.3    0.015    0.00429      46.57                     16    19
  19      2500.    1200.    39241.9    0.015    0.00052      32.70                     16    17
   •        •        •         •         •         •           •                        •     •
   •        •        •         •         •         •           •                        •     •
   •        •        •         •         •         •           •                        •     •
 160      2500.    1200.    18982.2    0.015    0.03765      15.82                    107   108
 161      2100.    2400.    83246.6    0.015   -0.00253      34.69                     52   108
 162      2100.    1300.    20571.3    0.015    0.02363      15.82                    108   109
 163      2100.    1200.    40590.1    0.015    0.00734      33.82                     54   109
 164      2100.    1600.    25329.2    0.015    0.03015      15.83                    109   110
 165      2100.    1100.    32809.0    0.015   -0.02262      29.83                     56   110
 166      1950.    1300.    43980.0    0.015    0.01188      33.83                     56    58
 167      2100.    1450.    22960.2    0.015    0.02221      15.83                     58    60
 168      1950.    1800.    57309.5    0.015   -0.00858      31.84                     59    60
 169      1650.    1500.    25253.2    0.015    0.02633      16.84                     57    59
 170      2500.    2500.    74775.0    0.015    0.0          29.91                    111   112

TAPE 10 WAS WRITTEN FROM CYCLE      0 TO CYCLE   1800



END OF TWO-DIMENSIONAL EXPLICIT PROGRAM. 1800 CYCLES.
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SAN DIEGO BAY HYDRAULICS WITH MEAN ANNUAL TIDE(25.0 HOUR PERIOD)                    FEDERAL WATER QUALITY ADMINISTRATION
DEMONSTRATION RUN FOR DOCUMENTATION REPORT            05-27-70                      NET FLOWS AND HYDRAULIC SUMMARY
EXTRACT HYDRAULIC RUN AFTER 50.0 HOURS USING 0.50 HOUR TIME STEP
THIS EXTRACT COMPLETED AS PART OF HYDRAULIC RUN ON 05-27-70


******** FROM HYDRAULICS PROGRAM ********     HYDRAULIC CYCLES PER     TIME INTERVAL IN
START CYCLE    STOP CYCLE    TIME INTERVAL        QUALITY CYCLE         QUALITY PROGRAM

     0            1800        50.  SECONDS             36                 0.50  HOURS



                              * * * * *  FLOW  * * * * *         * *   VELOCITY   * *         * * *  CROSS-SECTIONAL AREA  * * *
CHANNEL      NET FLOW           MIN.              MAX.             MIN.         MAX.             MIN.          MAX.          AVE.
NUMBER        (CFS)            (CFS)             (CFS)            (FPS)        (FPS)          (SQ. FT)      (SQ. FT)      (SQ. FT)

    1        -340.56       -200798.00        150913.44          -1.562        1.214          119837.8      143589.2      131968.9
    2           0.0              0.0              0.0            0.0          0.0            75086.5       88334.1       81966.1
    3        -343.78       -197372.00        148223.81          -1.725        1.343          105939.5      129192.0      117558.3
    4        -364.31       -193546.56        145244.94          -2.283        1.750           81776.9       91245.8       86481.5
    5        -663.24       -143164.25        107340.31          -1.453        1.117           93956.4      107329.6      100634.9
    6         295.56        -47683.69         35828.89          -0.856        0.662           52893.1       61254.5       57076.0
    7         294.57        -46485.11         34911.03          -0.881        0.682           49885.8       58269.9       54076.0
    8        -504.91       -115814.19         86392.50          -1.172        0.896           94324.6      107483.1      100881.4
    9        -160.06        -25317.88         19395.25          -0.302        0.237           79488.6       91802.0       85619.3
   10         134.28        -70522.94         53329.72          -1.478        1.148           45309.8       52296.4       48808.9
   11        -506.21       -113799.31         84861.25          -1.205        0.922           89996.9      102913.3       96428.4
   12        -374.62       -177460.81        133002.56          -1.579        1.216          106801.3      122522.7      114661.0
   13         132.22        -66111.81         49994.91          -0.637        0.495           99002.4      112198.0      105579.4
   14           1.34         -3273.50          2590.66          -0.546        0.402            8598.6       12209.8       10423.3
   15           0.96         -2426.37          1919.84          -0.151        0.125           25152.6       34379.4       29787.2
   16           0.30          -769.53           608.78          -0.043        0.039           27817.0       39632.0       33718.2

    •            •               •                •               •             •                •             •             •
    •            •               •                •               •             •                •             •             •
    •            •               •                •               •             •                •             •             •

  160         547.07         -8247.88          7201.46          -0.540        0.523           12172.3       19103.8       15658.0
  161        -158.31         -2237.70          1478.21          -0.030        0.020           69681.3       83585.3       76638.9
  162         391.38         -9409.29          7865.35          -0.568        0.528           13182.6       20707.0       16964.3
  163         108.90         -1088.35          1517.21          -0.031        0.043           33764.9       40717.6       37255.3
  164         503.24         -6706.56          5871.29          -0.331        0.320           16223.8       25498.1       20884.0
  165        -506.29         -4927.70          5462.61          -0.177        0.186           26546.3       32928.5       29749.2
  166         157.71         -5953.93          4637.16          -0.151        0.122           36574.7       44121.3       40361.9
  167         159.49         -5237.50          4093.89          -0.287        0.246           14695.5       23118.3       18924.9
  168        -162.10         -3303.18          4194.99          -0.067        0.081           47044.3       57505.8       52295.7
  169         631.85         -6910.03          6293.24          -0.334        0.337           16701.8       25417.1       21077.7
  170           0.0              0.0              0.0            0.0          0.0            74887.5       74999.9       74936.6
```

| JUNCTION NUMBER | MINIMUM HEAD (FT) | OCCURS AT CYCLE | MAXIMUM HEAD (FT) | OCCURS AT CYCLE | AVERAGE HEAD (FT) | TIDAL RANGE (FT) |
|---|---|---|---|---|---|---|
| 1 | -2.69 | 520 | 2.60 | 0 | 0.07 | 5.29 |
| 2 | -2.69 | 520 | 2.60 | 0 | 0.07 | 5.29 |
| 3 | -2.70 | 521 | 2.78 | 3 | 0.07 | 5.48 |
| 4 | -2.71 | 522 | 2.86 | 3 | 0.07 | 5.57 |
| 5 | -2.72 | 524 | 2.83 | 5 | 0.07 | 5.56 |
| 6 | -2.73 | 525 | 2.85 | 7 | 0.07 | 5.58 |
| 7 | -2.73 | 525 | 2.86 | 6 | 0.07 | 5.59 |
| 8 | -2.73 | 526 | 2.86 | 7 | 0.07 | 5.59 |
| 9 | -2.74 | 526 | 2.86 | 8 | 0.07 | 5.60 |
| 10 | -2.74 | 527 | 2.85 | 8 | 0.07 | 5.59 |
| 11 | -2.74 | 527 | 2.86 | 9 | 0.07 | 5.61 |
| 12 | -2.74 | 527 | 2.82 | 15 | 0.07 | 5.56 |
| 13 | -2.74 | 527 | 2.87 | 15 | 0.07 | 5.61 |
| 14 | -2.75 | 528 | 2.89 | 15 | 0.07 | 5.63 |
| 15 | -2.75 | 528 | 2.85 | 10 | 0.07 | 5.60 |
| 16 | -2.76 | 530 | 2.82 | 11 | 0.07 | 5.59 |
| 17 | -2.76 | 530 | 2.86 | 14 | 0.07 | 5.62 |
| 18 | -2.76 | 530 | 2.89 | 14 | 0.07 | 5.65 |
| 19 | -2.77 | 531 | 2.82 | 13 | 0.07 | 5.59 |
| 20 | -2.77 | 530 | 2.82 | 12 | 0.07 | 5.59 |
| 21 | -2.77 | 531 | 2.82 | 13 | 0.07 | 5.59 |
| 22 | -2.77 | 531 | 2.79 | 15 | 0.07 | 5.56 |
| 23 | -2.77 | 531 | 2.81 | 20 | 0.07 | 5.58 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 95 | -2.89 | 552 | 3.01 | 0 | 0.07 | 5.90 |
| 96 | -2.91 | 557 | 3.02 | 0 | 0.07 | 5.93 |
| 97 | -2.90 | 555 | 3.02 | 0 | 0.07 | 5.92 |
| 98 | -2.90 | 554 | 3.01 | 0 | 0.07 | 5.91 |
| 99 | -2.91 | 557 | 3.02 | 0 | 0.07 | 5.93 |
| 100 | -2.91 | 556 | 3.02 | 0 | 0.07 | 5.92 |
| 101 | -2.90 | 555 | 3.02 | 0 | 0.07 | 5.92 |
| 102 | -2.92 | 560 | 3.03 | 0 | 0.07 | 5.95 |
| 103 | -2.94 | 566 | 3.03 | 0 | 0.07 | 5.98 |
| 104 | -2.82 | 540 | 2.90 | 0 | 0.07 | 5.72 |
| 105 | -2.83 | 541 | 2.91 | 0 | 0.07 | 5.74 |
| 106 | -2.83 | 541 | 2.92 | 0 | 0.07 | 5.75 |
| 107 | -2.84 | 543 | 2.93 | 0 | 0.07 | 5.77 |
| 108 | -2.84 | 544 | 2.94 | 0 | 0.07 | 5.78 |
| 109 | -2.85 | 545 | 2.95 | 0 | 0.07 | 5.80 |
| 110 | -2.85 | 545 | 2.95 | 0 | 0.07 | 5.80 |
| 111 | -3.01 | 1800 | -3.00 | 0 | -3.01 | 0.01 |
| 112 | -3.01 | 1800 | -3.00 | 0 | -3.01 | 0.01 |

```
**** OUTPUT FOR CHECKING DATA ON EXTRACTED TAPE ****

HYDRAULIC     HEAD AT          *FLOW IN CHANNEL*
  CYCLE    JUNCTION NO.1      NO.1          NO.2

     0         2.60        -71820.00        0.0
    36         2.54        -93625.56        0.0
    72         2.35        -76629.88        0.0
   108         2.05        -71167.63        0.0
   144         1.64        -84553.56        0.0
   180         1.16       -134856.06        0.0
   216         0.61       -178309.88        0.0
   252         0.04       -200798.00        0.0
   288        -0.53       -188441.63        0.0
   324        -1.08       -151712.81        0.0
     .          .               .            .
     .          .               .            .
     .          .               .            .
   936         1.25         52801.16        0.0
   972         1.37         15694.23        0.0
  1008         1.39        -28763.05        0.0
  1044         1.30        -67205.00        0.0
  1080         1.12        -90490.31        0.0
  1116         0.86        -97496.31        0.0
  1152         0.54        -94650.75        0.0
  1188         0.20        -89584.31        0.0
  1224        -0.14        -84433.75        0.0
  1260        -0.44        -76900.19        0.0
  1296        -0.68        -61057.69        0.0
  1332        -0.84        -33219.55        0.0
  1368        -0.89          5898.60        0.0
  1404        -0.83         50700.91        0.0
  1440        -0.66         90866.88        0.0
  1476        -0.39        117790.13        0.0
  1512        -0.04        129040.50        0.0
  1548         0.38        128225.88        0.0
  1584         0.83        122350.75        0.0
  1620         1.28        115867.88        0.0
  1656         1.71        107984.56        0.0
  1692         2.08         93238.63        0.0
  1728         2.36         66040.13        0.0
  1764         2.54         26010.03        0.0



END OF NET FLOW PROGRAM.
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PROGRAM DYNQUA

```
C                 FEDERAL WATER QUALITY ADMINISTRATION
C                     DYNAMIC WATER QUALITY MODEL
C                        QUARTER-POINT VERSION
C
C*********************************************************************
C
C        THE PROGRAM LOGIC IN THIS DECK WAS DEVELOPED FOR THE NETWORKS
C        REPRESENTING THE SAN FRANCISCO BAY-DELTA AND THE SAN DIEGO BAY
C        SYSTEMS WHEREIN A SINGLE QUALITY CONDITION IS SPECIFIED
C        SIMULTANEOUSLY AT TWO NODES(NUMBERED 1 AND 2) AT THE SEAWARD
C        BOUNDARY.  APPLICATION TO OTHER SYSTEMS MAY REQUIRE PROGRAM
C        MODIFICATION.  SUBROUTINE ZONES IS SPECIFIC TO THE SAN DIEGO
C        BAY NETWORK.
C
C*********************************************************************
C
      DIMENSION DECAY(5),REOXK(5),NCONDK(5),NCONOX(5),CSAT(5),ODECAY(5),
     * NGROUP(10),FACTR(5,10),NJSTRT(5,10),NJSTOP(5,10),KBOP(5)
      DIMENSION JDIV1(20),JDIV2(20),JRET1(20),JRET2(20),RETFAC (20,5),
     *      CONST(20,5),AVOL(840),CAVE(840,5)
      DIMENSION YNEW(840),VOLQIN(840),C(840,5),CSPEC(840,5),QNET(1300),
     *    CIN(5,840),VOL(840),ASUR(840),QINWQ(840),CMASS(840,5),
     *          DIFFK(1300),ALPHA(220),CLIMIT(5),JPRT(50)
      DIMENSION Y(840),AREAS(840),QIN(840),NCHAN(840,5),V(1300),Q(1300),
     *   AREA(1300),B(1300),CLEN(1300),R(1300),CN(1300),NJUNC(1300,2)
      COMMON ALPHA,NSPEC,DELTQ,NUMCON,NALPHA,NJ,ASUR,MARK1,MARK2,KDONE,
     *       KZOP,CAVE,AVOL
      EQUIVALENCE (AREAS,ASUR),(QIN,QINWQ,VOLQIN),(CN,DIFFK),
     *            (CMASS,NCHAN),(YNEW,AREA),(AVOL,QNET)

C*****        CONTROL OPTIONS       *****

C*****  KDCOP = 1,2  PRINT DEPLETION CORRECTIONS, OR NOT
C*****  KBOP(M) = 1,2 SEAWARD BOUNDARY CONCENTRATION FOR CONSTITUENT M
C                     IS CONSTANT, OR VARIABLE OVER TIDAL CYCLE
C*****  KZOP = 1,2  QUALITY EXTRACT CALLS ZONES ROUTINE, OR NOT

      REWIND 3
      REWIND 9
      REWIND 10

C**** READ SYSTEM INFORMATION FROM DYNAMIC FLOW PROGRAM

      READ(5,80) NJ,NC,NSTART,NSTOP,NODYN
   80 FORMAT(7I5)
      K = (NSTOP-NSTART)/NODYN
      DO 86 I = 1,K
      READ(3)      ICYCTF,(YNEW(J),J=1,NJ)
      READ(3)      (Q(N),V(N),N=1,NC)
   86 CONTINUE
      READ(3)      (QNET(N),N=1,NC)
      READ(3)         (ALPHA(I),I=1,40),NJ,NC,DELT,(CN(N),R(N),B(N),
     *    CLEN(N),N=1,NC)
      READ(3)         (Y(J),AREAS(J),QIN(J),(NCHAN(J,K),K=1,5),J=1,NJ),
     *    (AREA(N),     (NJUNC(N,I),I=1,2),N=1,NC)
      REWIND 3
```

```
C**** READ INDEPENDENT CONTROL DATA

      READ(5,84) NRSTRT,INCYC,NQCYC,KZOP ,KDCOP,NTAG,CDIFFK
   84 FORMAT(6I5,F10.0)
      READ(5,80)  IPRT,NQPRT,NEXTPR,INTBIG,IWRITE,NEXTWR,IWRINT
      READ(5,103)(ALPHA(I),I=41,80)
  103 FORMAT(20A4)
      WRITE(6,105) (ALPHA(I),I=1,80)
  105 FORMAT(1H1////
     *  1H 20A4,14X,37H FEDERAL WATER QUALITY ADMINISTRATION/
     *  1H 20A4,14X,28H DYNAMIC WATER QUALITY MODEL/
     *        1H 20A4/1H 20A4////)
      DELTQ1=DELT*FLOAT (NODYN)/3600.0
      DELTQ2=DELTQ1*FLOAT (NQPRT)
      WRITE(6,106) NSTART,NSTOP,DELT
  106 FORMAT(42H ******** FROM HYDRAULICS PROGRAM ********/
     *        42H START CYCLE   STOP CYCLE    TIME INTERVAL//
     *         1H I7,I14,F12.0,9H  SECONDS/////)
      WRITE(6,107)NRSTRT,INCYC,NQCYC,INTBIG,DELTQ2,DELTQ1,CDIFFK
  107 FORMAT(117H    STARTING CYCLE    INITIAL QUALITY  TOTAL QUALITY  *
     *** OUTPUT INTERVALS ***    TIME INTERVAL IN       CONSTANT FOR/
     *        122H ON HYD. EXTRACT TAPE       CYCLE           CYCLES
     * CYCLES        HOURS        QUALITY PROGRAM   DIFFUSION COEFFICIENT
     *S//
     *     I13,I18,I16,I13,F14.2,F17.3,6H HOURS,F17.3////)
      WRITE(6,109) IPRT,IWRITE
  109 FORMAT(31H PRINTOUT IS TO BEGIN AT CYCLE I4//
     *      49H QUALITY TAPE FOR EXTRACTING IS TO BEGIN AT CYCLEI5////)

C***** READ AND PRINT QUALITY COEFICIENTS

      DTD = DELTQ1 / 24.
      READ(5,112) NUMCON
      READ(5,40)            (NCONDK(K),NCONOX(K),K=1,NUMCON)
   40 FORMAT(10I5)
      DO 44 K=1,NUMCON
      IF(NCONDK(K))46,46,41
   41 READ(5,42) DECAY(K),REOXK(K),CSAT(K)
   42 FORMAT(3F10.0)
      DECAY(K) = EXP(-DECAY(K) * DTD)
      REOXK(K) = EXP(-REOXK(K) * DTD)
      REOXK(K) = 1.0 - REOXK(K)
      ODECAY(K) = 1.0 - DECAY(K)
   44 CONTINUE
   46 CONTINUE
      NALPHA = 120+ NUMCON * 20
      READ(5,103)           (ALPHA(I),I=121,NALPHA)
      READ(5,110) (CLIMIT(K),K=1,NUMCON)
  110 FORMAT(5F10.0)

      WRITE(6,120) NUMCON
  120 FORMAT(1H0I5,42H CONSTITUENTS BEING CONSIDERED IN THIS RUN//)
      WRITE(6,122)               (ALPHA(I),I=121,NALPHA)
  122 FORMAT(1H020A4)
      IF(NCONDK(1))48,48,51
   48 WRITE(6,50)
   50 FORMAT(1H0//
     *        53H0ALL CONSTITUENTS TREATED AS CONSERVATIVE IN THIS RUN//)
      GO TO 60
   51 DO 59 K=1,NUMCON
      IF(NCONDK(K))60,60,52
   52 IF(NCONOX(K))57,57,54
   54 WRITE(6,56)NCONDK(K),DECAY(K),NCONOX(K),REOXK(K),CSAT(K)
   56 FORMAT(1H0//17HOCONSTITUENT NO. I1,33H IS BOD WITH DECAY COFFFICIE
     *NT = F10.7,44H   THE ASSOCIATED OXYGEN IS CONSTITUENT NO. I1/31H W
     *ITH REAERATION COEFFICIENT = F15.9,32H AND SATURATION CONCENTRATIO
     *N = F10.2)
      GO TO 59
   57 WRITE(6,58) NCONDK(K),DECAY(K)
   58 FORMAT(1H0/
     *         17HOCONSTITUENT NO. I1,59H IS TREATED AS A NON-CONSERVATIVE
     * WITH DECAY COEFFICIENT = F10.7,45H BUT IS NOT PAIRED WITH ANY OTH
     *ER CONSTITUENT)
   59 CONTINUE
   60 CONTINUE

C***** READ WASTE WATER RETURN FACTORS

      READ(5,112) NUNITS
  112 FORMAT(I5)
      IF(NUNITS)118,118,114
  114 DO 117 I=1,NUNITS
      READ(5,116)             JDIV1(I),JDIV2(I),JRET1(I),JRET2(I),
     *   (RETFAC (I,M),CONST(I,M),M=1,NUMCON)
  116 FORMAT(I3,3I4,5(F5.0,E8.2))
  117 CONTINUE
  118 CONTINUE

C***** PRINT NETWORK AND HYDRAULIC PARAMETERS

      IF(NJ - NC)72,72,70
   70 N1 = NC
      N2 = NJ
      GO TO 74
   72 N1 = NJ
      N2 = NC
   74 WRITE(6,196)              (N,CLEN(N),B(N),AREA(N),CN(N),QNET(N),
     * R(N),(NJUNC(N,K),K=1,2),N,QIN(N),Y(N),(NCHAN(N,I),I=1,5),N=1,N1)
      N1 = N1 + 1
      IF(NJ - NC)76,79,78
   78 WRITE(6,195)      (J,QIN(J),Y(J),(NCHAN(J,K),K=1,5),J=N1,N2)
      GO TO 79
   76 WRITE(6,194)              (N,CLEN(N),B(N),AREA(N),CN(N),QNET(N),
     * R(N),(NJUNC(N,K),K=1,2),N=N1,N2)
  194 FORMAT(I5,2F8.0,F9.0,F8.3,F12.2,F10.1,I9,I6)
  195 FORMAT(82X,I5,F9.1,F7.2,I7,4I5)
  196 FORMAT(1H1////42X,48H *****      SUMMARY OF HYDRAULIC INPUTS      **
     ****//86H ** JUNCTION HEAD AND HYD. RADIUS AND X-SECTIONAL AREA OF
     *CHANNELS ARE AT MEAN TIDE **///
     *      132H*******************************    CHANNEL DATA    ********
     ***********************      ***************    JUNCTION DATA    ****
     ***********/
     *      132H CHAN.  LENGTH   WIDTH    AREA   MANNING  NET FLOW  HYD.
     *RADIUS  JUNC. AT ENDS      JUNC. INFLOW   HEAD   CHANNELS ENTERING
     * JUNCTION//
     * (I5,2F8.0,F9.0,F8.3,F12.2,F10.1,I9,I6,7X,I5,F9.1,F7.2,I7,4I5))
   79 CONTINUE

C***** READ INITIAL QUALITY CONDITIONS

      IF(NUMCON - 3)126,124,124
  124 NFIRST = 3
      GO TO 128
  126 NFIRST = NUMCON
  128 DO 206 J=1,NJ
      READ(5,200)           JJ,QINWQ(J),(C(J,K),CSPEC(J,K),K=1,NFIRST)
  200 FORMAT(I5,7F10.0)
      IF(JJ - J)202,206,202
  202 WRITE(6,204) JJ,J
  204 FORMAT(31HODATA CARD OUT OF SEQUENCE. JJ= I4,3H,J= I4)
      CALL EXIT
  206 CONTINUE
      IF(NUMCON - 3)212,212,207
  207 NFIRST = NFIRST + 1
      DO 210 J=1,NJ
      READ(5,200)           JJ, (C(J,K),CSPEC(J,K),K=NFIRST,NUMCON)
      IF(JJ - J)208,210,208
  208 WRITE(6,204) JJ,J
      CALL EXIT
  210 CONTINUE
  212 CONTINUE

C***** READ AND APPLY FACTORS TO ADJUST INITIAL CONCENTRATIONS

      DO 222 I=1,NUMCON
      READ(5,112) NGROUP (I)
      IF(NGROUP (I))222,222,218
  216 FORMAT(52HONO MULTIPLICATION FACTOR APPLIED TO CONSTITUENT NO.I2/)
  218 NG = NGROUP (I)
      READ(5,220)           (FACTR(I,K),NJSTRT (I,K),NJSTOP(I,K),K=1,NG)
  220 FORMAT(F5.0,2I5,F5.0,2I5,F5.0,2I5,F5.0,2I5,F5.0,2I5)
  222 CONTINUE
      WRITE(6,224)
  224 FORMAT(70H1*****MULTIPLICATION FACTORS APPLIED TO ORTAIN STARTING
     *CONCENTRATIONS//
     *        51H CONSTITUENT    GROUP    FACTOR    JUNCTION NUMBERS)
      DO 230 I=1,NUMCON
      IF(NGROUP (I))230,230,226
  226 NG = NGROUP (I)
      WRITE(6,228)I,(K,FACTR(I,K),NJSTRT (I,K),NJSTOP(I,K),K=1,NG)
  228 FORMAT(1H //I8,I11,F11.2,I12,2H -,I4/
     *   (I19,F11.2,I12,2H -,I4))
  230 CONTINUE
      DO 232 I=1,NUMCON
      IF(NGROUP (I))231,231,232
  231 WRITE(6,216)I
  232 CONTINUE
      DO 238 M=1,NUMCON
      IF(NGROUP (M))238,238,233
  233 NG = NGROUP (M)
      DO 236 K=1,NG
      NJ1 = NJSTRT (M,K)
      NJ2 = NJSTOP(M,K)
      DO 234 J=NJ1,NJ2
      C(J,M) = C(J,M) * FACTR(M,K)
  234 CONTINUE
  236 CONTINUE
  238 CONTINUE

C***** PRINT INITIAL QUALITY CONDITIONS

      WRITE(6,241)
  241 FORMAT(1H1////
     *      120H**********************************************     WATER
     *QUALITY DATA     *************************************************/
     *      120H                    * FIRST CONSTITUENT * SECOND CONSTITUENT
     * * THIRD CONSTITUENT * FOURTH CONSTITUENT * FIFTH CONSTITUENT */
     *      118H                         INITIAL    INFLOW   INITIAL     INFLOW
     *   INITIAL    INFLOW   INITIAL      INFLOW   INITIAL     INFLOW/
     *     119H JUNC.   INFLOW      CONC.       CONC.     CONC.        CONC.
     *    CONC.      CONC.     CONC.        CONC.     CONC.       CONC.//)
      DO 283 J=1,NJ
      WRITE(6,282)              J,QINWQ(J),(C(J,K),CSPEC(J,K),K=1,NUMCON)
  282 FORMAT(I4,F10.1,F12.2,2F10.2,F11.2,3F10.2,F11.2,2F10.2)
  283 CONTINUE

C***** READ AND PRINT BOUNDARY CONCENTRATIONS

      READ(5,80)(KBOP(M),M=1,NUMCON)
      READ(5,112) NSPEC
      DO 187 M=1,NUMCON
      L = KBOP(M)
      GO TO(185,183),L
  183 READ(5,184)(CIN(M,I),I=1,NSPEC)
  184 FORMAT(7F10.0)
      GO TO 187
  185 READ(5,184) CIN(M,1)
      DO 186 I=2,NSPEC
      CIN(M,I) = CIN(M,1)
  186 CONTINUE
  187 CONTINUE


      DO 190 M=1,NUMCON
      WRITE(6,188)            M,(CIN(M,I),I=1,NSPEC)
  188 FORMAT(55HOSPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. I
     *1//
     *  (1H 7F12.3))
  190 CONTINUE

C***** READ LIST OF JUNCTIONS FOR PRINTOUT

      READ(5,112) NOPRT
      READ(5,192)(JPRT(I),I=1,NOPRT)
  192 FORMAT(14I5)

C***** PRINT WASTE WATER RETURN FACTORS

      IF(NUNITS.GT.0)GO TO 197
      WRITE(6,81)
   81 FORMAT(38HONO WASTE WATER RETURN FACTORS APPLIED//)
      GO TO 353
  197 WRITE(6,198)
  198 FORMAT(1H1////
     *      132H*********************************************      TABLE O
     *F WASTE WATER RETURN FACTORS     ********************************
     ***********/
     *       37H      JUNCTIONS USED   JUNCTIONS USED/
     *      132H      FOR DIVERSIONS   FOR RET. FLOWS   1ST. CONSTITUENT
     *  2ND. CONSTITUENT   3RD. CONSTITUENT   4TH. CONSTITUENT   5TH. CO
     *NSTITUENT/
     *      132H UNIT  NO. 1  NO. 2     NO. 1  NO. 2    COEFF.    CONST.
     *  COEFF.   CONST.   COEFF.    CONST.   COEFF.    CONST.   COEFF.
     *   CONST.//)
```

```
      DO 352 I=1,NUNITS
      WRITE(6,350)             I,JDIV1(I),JDIV2(I),JRET1(I),JRET2(I),
     * (RETFAC (I,M),CONST(I,M),M=1,NUMCON)
  350 FORMAT(I3,I8,I7,I10,I7,F9.2,E12.2,4(F7.2,E12.2))
  352 CONTINUE
  353 CONTINUE

C**** INITIALIZATION

      KDONE = 0
      MARK1 = 0
      MARK2 = 0
      DELTQ=DELT*FLOAT (NODYN)
      NCOUNT = 0
      KOUNTT = 0
      NTEMP = NSTOP - NODYN
      DO 358 N=1,NC
      IF(NJUNC(N,1)-NJUNC(N,2))358,358,357
  357 KEEP=NJUNC(N,1)
      NJUNC(N,1)=NJUNC(N,2)
      NJUNC(N,2)=KEEP
  358 CONTINUE

C***** CALCULATE MEAN JUNCTION VOLUMES

  359 DO 373 J=1,NJ
      AVOL(J) = 0.0
      ASUM   = 0.0
      DSUM   = 0.0
      DO 371 K=1,5
      IF (NCHAN(J,K)) 372,372,370
  370 N    = NCHAN(J,K)
      ABAR = CLEN(N)*B(N)
      ASUM = ASUM + ABAR
      DSUM = DSUM + ABAR*R(N)
  371 CONTINUE
  372 DBAR = DSUM/ASUM
      AVOL(J) = ASUR(J) * DBAR
  373 CONTINUE

C***** CORRECT VOLUMES FOR INITIAL STARTING CONDITIONS

  774 READ(3)      ICYCTF,(YNEW(J),J=1,NJ)
      IF(ICYCTF-NRSTRT)775,776,776
  775 READ(3)    (Q(N),V(N) ,N=1,NC)
      GO TO 774
  776 DO 780 J=1,NJ
      VOL(J) =AVOL(J) + ASUR(J)*(YNEW(J)-Y(J))
      Y(J)   = YNEW(J)
  780 CONTINUE

C***** CALCULATE INITIAL MASS

      DO 378 J=1,NJ
      DO 377 K=1,NUMCON
      CMASS(J,K)= C(J,K) * VOL(J)
  377 CONTINUE
  378 CONTINUE

C**** EDDY DIFFUSION CONSTANT

      DO 385 N=1,NC
  385 DIFFK(N)=CDIFFK*R(N)*DELTQ/CLEN(N)

C***** COMPUTE VOLUMES OF INFLOW-OUTFLOW

      DO 388 J=1,NJ
      VOLQIN(J) = QINWQ(J) * DELTQ
  388 CONTINUE

C***** STORE INITIAL CONDITIONS TO EXTRACT FIRST TIDAL CYCLE

      IF(IWRITE.GE.INCYC)GO TO 34
      WRITE(10)      IWRITE,((C(J,K),K=1,NUMCON),J=1,NJ)
      MARK1 = IWRITE
      KOUNTT = KOUNTT + 1
   34 CONTINUE
C***********************************************************************
C                       MAIN QUALITY LOOP
C***********************************************************************
      DO 536 ICYC=INCYC,NQCYC
      NQCYCC = ICYC

C*****READ SYSTEM CONDITIONS

      READ(3)     (Q(N),V(N) ,N=1,NC)
      IF (ICYCTF-NTEMP) 790,794,794
  790 READ(3)      ICYCTF,(YNEW(J),J=1,NJ)
      GO TO 407
  794 REWIND 3
      READ(3)      ICYCTF,(YNEW(J),J=1,NJ)
  407 CONTINUE

C***** DETERMINE FLOW DIRECTION AND COMPUTE 1/4 POINT CONCENTRATION

      DO 416 N=1,NC
      VOLFLW = Q(N) * DELTQ
      NL = NJUNC(N,1)
      NH = NJUNC(N,2)
      IF(N.GT.2) GO TO 406
      IF(Q(N))402,404,404
  402 FACTOR = 0.0
      GO TO 412
  404 FACTOR = 1.0
      GO TO 412
  406 IF(Q(N))408,410,410
  408 FACTOR = 0.25
      GO TO 412
  410 FACTOR = 0.75

  412 DO 414 K=1,NUMCON
      QGRAD = C(NL,K) - C(NH,K)
      CONC = C(NH,K) + FACTOR * QGRAD

C***** ADVECTION AND DIFFUSION

      ADMASS = CONC * VOLFLW
      DIMASS = DIFFK(N) * ABS (Q(N)) * QGRAD
      CMASS(NH,K) = CMASS(NH,K) + ADMASS + DIMASS
      CMASS(NL,K) = CMASS(NL,K) - ADMASS - DIMASS
  414 CONTINUE
  416 CONTINUE

C**** DECAY AND MASS TRANSFER

```

```
      IF(NCONDK(1))424,424,417
  417 DO 422 K=1,NUMCON
      IF(NCONDK(K))424,424,418
  418 NCON = NCONDK(K)
      NCONO = NCONOX(K)
      DO 420 J=3,NJ
      CMASS(J,NCON)=CMASS(J,NCON) * DECAY(K)
      IF(NCONO)420,420,419
  419 CMASS(J,NCONO) = CMASS(J,NCONO) - C(J,NCON) * VOL(J) * ODECAY(K)
     *  + REOXK(K) *          VOL(J) * (CSAT(K) - C(J,NCONO))
  420 CONTINUE
  422 CONTINUE
  424 CONTINUE

C***** WASTE DISCHARGES AND DIVERSIONS

      DO 434 J=3,NJ
      IF(VOLOIN(J))430,434,432
  430 DO 431 K=1,NUMCON
      CMASS(J,K)=CMASS(J,K) - CSPEC(J,K) * VOLOIN(J)
  431 CONTINUE
      GO TO 434
  432 DO 433 K=1,NUMCON
      CMASS(J,K)=CMASS(J,K) - C(J,K) * VOLOIN(J)
  433 CONTINUE
  434 CONTINUE

C***** APPLY WASTE WATER RETURN FACTORS

      IF(NUNITS)442,442,436
  436 DO 440 I=1,NUNITS
      JD1 = JDIV1(I)
      JD2 = JDIV2(I)
      JR1 = JRET1(I)
      JR2 = JRET2(I)
      DO 438 M=1,NUMCON
      CMASS(JR1,M)=CMASS(JR1,M)+(C(JD1,M)*VOLOIN(JD1)*RETFAC (I,M))+
     *   CONST(I,M)
      CMASS(JR2,M)=CMASS(JR2,M)+(C(JD2,M)*VOLOIN(JD2)*RETFAC (I,M))+
     *   CONST(I,M)
  438 CONTINUE
  440 CONTINUE
  442 CONTINUE

C***** CORRECT JUNCTION VOLUME AND FIND NEW CONCENTRATION FACTOR

      NTAG = NTAG + 1
      IF(NTAG - NSPEC)428,426,426
  426 NTAG = 0
  428 DO 429 K=1,NUMCON
      C(1,K) = CIN(K,NTAG+1)
      C(2,K) = C(1,K)
  429 CONTINUE
      DO 446 J=3,NJ
      VOL(J) = VOL(J) + ASUR(J) * (YNEW(J) - Y(J))
      DO 444 K=1,NUMCON
      C(J,K) =CMASS(J,K) / VOL(J)
  444 CONTINUE
  446 CONTINUE

C***** PREVENT NEGATIVE CONCENTRATION AND SUPERSATURATION

```

```
      DO 466 J=1,NJ
      Y(J) = YNEW(J)
      DO 464 K=1,NUMCON
      IF(C(J,K))451,464,464
  451 GO TO(452,462),KDCOP
  452 IF((ICYC+ NSPEC + 1) - NQCYC)462,458,458
  458 WRITE(6,460)          J,ICYC,K,C(J,K)
  460 FORMAT(39H DEPLETION CORRECTION MADE AT JUNCTION I3,7H CYCLE I4,
     * 21H FOR CONSTITUENT NO. I1,12H. CONC. WAS F10.2)
  462 C(J,K) = 0.0
      CMASS(J,K)= 0.0
  464 CONTINUE
  466 CONTINUE
      IF(NCONDK(1))479,479,470
  470 DO 476 K=1,NUMCON
      IF(NCONDK(K))476,476,471
  471 IF(NCONOX(K))476,476,472
  472 NCON = NCONOX(K)
      DO 475 J=1,NJ
      IF(C(J,NCON) - CSAT(K))475,475,473
  473 WRITE(6,474)          NCON,J,ICYC,C(J,NCON)
  474 FORMAT(36HOSUPERSATURATION OF CONSTITUENT NO. I1,23H PREVENTED AT
     *JUNCTION I4,7H CYCLE I4,10H CONC. WAS F10.2//)
      C(J,NCON) = CSAT(K)
      CMASS(J,NCON) = C(J,NCON) * VOL(J)
  475 CONTINUE
  476 CONTINUE
  479 CONTINUE

C***** CHECK CONCENTRATIONS AGAINST SPECIFIED LIMITS

      DO 482 J=1,NJ
      DO 480 K=1,NUMCON
      IF(C(J,K) - CLIMIT(K))480,480,477
  477 WRITE(6,478)          K,CLIMIT(K),J,ICYC
  478 FORMAT(34HOCONCENTRATION OF CONSTITUENT NO. I1,8H EXCEEDS,F7.1,
     * 13H IN JUNCTION I3,14H DURING CYCLE I5,25H.   EXECUTION TERMINATE
     *D.)
      WRITE(6,481) ((C(L,M),M=1,NUMCON),L=1,NJ)
  481 FORMAT(1H 8E16.8)
      CALL EXIT
  480 CONTINUE
  482 CONTINUE

C***** WRITE BINARY TAPE FOR EXTRACTING

      IF((ICYC+NSPEC)-NQCYC)486,484,490
  484 KOUNTT = 0
      REWIND 10
      GO TO 490
  486 IF(ICYC.LT.IWRITE)GO TO 500
  490 KOUNTT = KOUNTT +1
      IF(KOUNTT.GT.1)GO TO 494
      MARK1 = ICYC
  494 IF(KOUNTT.LT.(NSPEC+1))GO TO 498
      MARK2 = ICYC
      KOUNTT=0
      KDONE = 1
      IWRITE = NEXTWR
      NEXTWR = NEXTWR + IWRINT
  498 WRITE(10)      ICYC,((C(J,K),K=1,NUMCON),J=1,NJ)
  500 CONTINUE
```

```
C***** STORE OR UPDATE FOR RESTARTING

      IF(ICYC.EQ.NQCYC)GO TO 512
      IF(KDONE.EQ.0) GO TO 520
  512 WRITE(9) (ALPHA(I),I=1,80)
      WRITE(9) (VOLQIN(J),(C(J,K),CSPEC(J,K),K=1,NUMCON),J=1,NJ)
      WRITE(6,518)             ICYC,ICYCTF,NTAG
  518 FORMAT(1H1///47H RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLEI5/
     *       50H HYDRAULIC CYCLE ON EXTRACT TAPE FOR RESTARTING = I5/
     *     8H NTAG = I3///)
      REWIND 9
  520 CONTINUE

C***** PRINT QUALITY OUTPUT OVER TIDAL CYCLE

      IF((ICYC + NSPEC + 1) - NQCYC)522,528,528
  522 IF(ICYC - IPRT)535,524,524
  524 IPRT = IPRT +NQPRT
      NCOUNT = NCOUNT + 1
      IF(NCOUNT - ((NSPEC / NQPRT) + 1))528,526,526
  526 NCOUNT = 0
      IPRT = NEXTPR
      NEXTPR = NEXTPR + INTBIG
  528 HOURS = DELTQ * FLOAT (ICYC) / 3600.0
      KDAYS = HOURS / 23.99999
      HOURS = HOURS - FLOAT (24 * KDAYS)
      WRITE(6,530) ICYC,KDAYS,HOURS
  530 FORMAT(1H1////
     *       35H SYSTEM STATUS AFTER QUALITY CYCLE I4,I12,6H DAYS,
     * F6.2,6H HOURS//
     *      109H                            ***************************
     *  CONCENTRATION FACTORS    ***************************/
     *      109H JUNCTION     HEAD           1ST. CONSTIT.    2ND. CONSTI
     *T.    3RD. CONSTIT.    4TH. CONSTIT.    5TH. CONSTIT./
     *      105H  NUMBER      (FT)              (MGL)              (MGL)
     *          (MGL)              (MGL)              (MGL)/)
      DO 534 I=1,NOPRT
      J=JPRT(I)
      WRITE(6,532)           J,Y(J),(C(J,K),K=1,NUMCON)
  532 FORMAT(1H0I5,F12.4,F20.2,4F17.2)
  534 CONTINUE
  535 IF(KDONE.EQ.1) CALL QUALEX
  536 CONTINUE

C***** EXIT

      REWIND 3
      REWIND 9
      CALL PUNCH
      WRITE(6,542) NQCYCC
  542 FORMAT(20H0END OF QUALITY RUN.,I5,9H  CYCLES.)
      CALL EXIT
      END
      SUBROUTINE QUALEX
      DIMENSION CX( 840,5),               CMIN( 840,5),CMAX( 840,5),
     *  CAVE( 840,5),AVOL( 840),                ASUR( 840),ALPHA(220)
      COMMON ALPHA,NSPEC,DELTQ,NUMCON,NALPHA,NJ,ASUR,MARK1,MARK2,KDONE,
     *        KZOP,CAVE,AVOL

      REWIND 10

C***** PRINT SUMMARY HEADING

      HOURS1 = DELTQ * FLOAT (MARK1 ) / 3600.0
      HOURS2 = HOURS1 + (FLOAT (NSPEC)*DELTQ/3600.)
      KDAYS2 = HOURS2 / 24.0
      HOURS1 = HOURS1 - FLOAT (24 * KDAYS1)
      HOURS2 = HOURS2 - FLOAT (24 * KDAYS2)
      WRITE(6,111) MARK1,KDAYS1,HOURS1,MARK2,KDAYS2,HOURS2
  111 FORMAT(1H1////72H***************************     QUALITY SUMMARY    *
     **************************/
     *  55H SUMMARY STARTS AT                          SUMMARY ENDS AT/
     *   6H CYCLE,I5,2H (,I3,5H DAYS,F5.1,7H HOURS),12H       CYCLE,
     *   I5,2H (,I3,5H DAYS,F5.1,7H HOURS)/////)
  112 WRITE(6,113)             (ALPHA(I),I=121,NALPHA)
  113 FORMAT(1H020A4)

C**** EXTRACT QUALITY TAPE

  114 READ(10)   ICYCQ,((CX(J,K),K=1,NUMCON),J=1,NJ)
      IF(ICYCQ - MARK1)114,115,118
  115 DO 117 J=1,NJ
      DO 116 K=1,NUMCON
      CAVE(J,K) = 0.5 *CX(J,K)
      CMIN(J,K) =CX(J,K)
      CMAX(J,K) =CX(J,K)
  116 CONTINUE
  117 CONTINUE
      GO TO 114
  118 DO 124 J=1,NJ
      DO 122 K=1,NUMCON
      CAVE(J,K) = CAVE(J,K) +CX(J,K)
      IF(CMIN(J,K) -CX(J,K))120,119,119
  119 CMIN(J,K) =CX(J,K)
      GO TO 122
  120 IF(CMAX(J,K) -CX(J,K))121,121,122
  121 CMAX(J,K) =CX(J,K)
  122 CONTINUE
  124 CONTINUE
      IF(ICYCQ- MARK2)114,126,126
  126 DO 130 J=1,NJ
      DO 128 K=1,NUMCON
      CAVE(J,K) = CAVE(J,K) - 0.5 *CX(J,K)
      CAVE(J,K) = CAVE(J,K) / FLOAT (MARK2 - MARK1)
  128 CONTINUE
  130 CONTINUE
      WRITE(6,131)
  131 FORMAT(1H ////
     *     132H          ** CONSTITUENT NO. 1 **  ** CONSTITUENT NO. 2 **
     *  ** CONSTITUENT NO. 3 **  ** CONSTITUENT NO. 4 **  ** CONSTITUENT
     * NO. 5 **/
     *     131HJUNC.      MIN.    MAX.    AVE.     MIN.     MAX.    AVE.
     *    MIN.    MAX.    AVE.     MIN.     MAX.    AVE.     MIN.    MAX.
     *    AVE.//)
      DO 133 J=1,NJ
      WRITE(6,132) J,(CMIN(J,K),CMAX(J,K),CAVE(J,K),K=1,NUMCON)
  132 FORMAT(I4,3X,(1X,3F8.2,1X,3F8.2,1X,3F8.2,1X,3F8.2,1X,3F8.2))
  133 CONTINUE

C***** COMPUTE AVERAGE CONCENTRATIONS IN SPECIFIED ZONES

      GO TO(140,150),KZOP
  140 CALL ZONES
  150 CONTINUE

C***** PREPARE FOR NEXT EXTRACT AND RETURN

      REWIND 10
      KDONE = 0
      RETURN
      END
```

```
      SUBROUTINE ZONES
C
C***********************************************************************
C
C           THIS SUBROUTINE IS SPECIFIC TO THE SAN DIEGO BAY NETWORK
C
C***********************************************************************
C
      DIMENSION CAVE( 840,5),TLBSC1(5),TLBSC2(5),TLBSC3(5),TLBSC4(5),
     *  TLBSC5(5),TLBSC6(5),TLBSCT(5),AVOL( 840),ASUR( 840),ALPHA(220),
     *  CAVE1(5),CAVE2(5),CAVE3(5),CAVE4(5),CAVE5(5),CAVE6(5),CAVET(5)
      COMMON ALPHA,NSPEC,DELTQ,NUMCON,NALPHA,NJ,ASUR,MARK1,MARK2,KDONE,
     *       KZOP,CAVE,AVOL

C*****  INITIALIZATION

      TVOL1 = 0.0
      TVOL2 = 0.0
      TVOL3 = 0.0
      TVOL4 = 0.0
      TVOL5 = 0.0
      TVOL6 = 0.0
      TVOLT = 0.0
      SAT = 0.0

C***** COMPUTE ZONE VOLUMES

      DO 96 J=1,NJ
      IF(J.LE.4.OR.J.GT.110)GO TO 96
      TVOLT = TVOLT +AVOL(J)
      IF(J.LE.9)GO TO 88
      IF(J.LE.34)GO TO 86
      IF(J.LE.58) GO TO 84
      IF(J.LE.103)GO TO 78
      IF(J.LE.106)GO TO 90
      GO TO 82
   78 TVOL1 = TVOL1 +AVOL(J)
      GO TO 96
   82 TVOL2 = TVOL2 +AVOL(J)
      GO TO 96
   84 TVOL3 = TVOL3 +AVOL(J)
      GO TO 96
   86 TVOL4 = TVOL4 +AVOL(J)
      GO TO 96
   88 TVOL5 = TVOL5 +AVOL(J)
      GO TO 96
   90 TVOL6 = TVOL6 +AVOL(J)
   96 CONTINUE

C***** COMPUTE TOTAL MASS IN EACH ZONE

      DO 134 I=1,NUMCON
      TLBSC1(I) = 0.0
      TLBSC2(I) = 0.0
      TLBSC3(I) = 0.0
      TLBSC4(I) = 0.0
      TLBSC5(I) = 0.0
      TLBSC6(I) = 0.0
      TLBSCT(I) = 0.0
  134 CONTINUE
      DO 156 J=1,NJ
      IF(J.LE.4.OR.J.GT.110) GO TO 156
      DO 154 I=1,NUMCON
      TLBSCT(I) = TLBSCT(I) + CAVE(J,I) *AVOL(J)
      IF(J.LE.9)GO TO 146
      IF(J.LE.34) GO TO 144
      IF(J.LE.58) GO TO 142
      IF(J.LE.103) GO TO 136
      IF(J.LE.106) GO TO 148
      GO TO 140
  136 TLBSC1(I) = TLBSC1(I) + CAVE(J,I) *AVOL(J)
      GO TO 154
  140 TLBSC2(I) = TLBSC2(I) + CAVE(J,I) *AVOL(J)
      GO TO 154
  142 TLBSC3(I) = TLBSC3(I) + CAVE(J,I) *AVOL(J)
      GO TO 154
  144 TLBSC4(I) = TLBSC4(I) + CAVE(J,I) *AVOL(J)
      GO TO 154
  146 TLBSC5(I) = TLBSC5(I) + CAVE(J,I) *AVOL(J)
      GO TO 154
  148 TLBSC6(I) = TLBSC6(I) + CAVE(J,I) *AVOL(J)
  154 CONTINUE
  156 CONTINUE

C***** COMPUTE MEAN CONCENTRATION IN EACH ZONE

      DO 158 I=1,NUMCON
      CAVE1(I) = TLBSC1(I) /TVOL1
      CAVE2(I) = TLBSC2(I) / TVOL2
      CAVE3(I) = TLBSC3(I) / TVOL3
      CAVE4(I) = TLBSC4(I) / TVOL4
      CAVE5(I) = TLBSC5(I) / TVOL5
      CAVE6(I) = TLBSC6(I) / TVOL6
      CAVET(I) = TLBSCT(I) / TVOLT
  158 CONTINUE
```

```
C***** PRINT ZONE CONCENTRATIONS

      DO 162 I=1,NUMCON
      WRITE(6,160)I,CAVE1(I),I,CAVE2(I),I,CAVE3(I),I,CAVE4(I),I,
     * CAVE5(I),I,CAVE6(I),I,CAVET(I)
  160 FORMAT(1H ////
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,16H IN ZONE NO. 1
     * =,F10.1,6H MG/L.//
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,16H IN ZONE NO. 2
     * =,F10.1,6H MG/L.//
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,16H IN ZONE NO. 3
     * =,F10.1,6H MG/L.//
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,16H IN ZONE NO. 4
     * =,F10.1,6H MG/L.//
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,16H IN ZONE NO. 5
     * =,F10.1,6H MG/L.//
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,16H IN ZONE NO. 6
     * =,F10.1,6H MG/L.//
     *  41HAVERAGE CONCENTRATION OF CONSTITUENT NO. I1,15H IN TOTAL BAY
     *=,F10.1,6H MG/L.///)
  162 CONTINUE

C***** PRINT ZONE VOLUMES

      WRITE(6,214) TVOL1,TVOL2,TVOL3,TVOL4,TVOL5,TVOL6,TVOLT
  214 FORMAT(28H0MEAN VOLUME OF ZONE NO. 1 =,E16.9,12H CUBIC FEET.//
     *       28H MEAN VOLUME OF ZONE NO. 2 =,E16.9,12H CUBIC FEET.//
     *       28H MEAN VOLUME OF ZONE NO. 3 =,E16.9,12H CUBIC FEET.//
     *       28H MEAN VOLUME OF ZONE NO. 4 =,E16.9,12H CUBIC FEET.//
     *       28H MEAN VOLUME OF ZONE NO. 5 =,E16.9,12H CUBIC FEET.//
     *       28H MEAN VOLUME OF ZONE NO. 6 =,E16.9,12H CUBIC FEET.//
     *       27H MEAN VOLUME OF TOTAL BAY =,E16.9,12H CUBIC FEET.//)

C***** COMPUTE AND PRINT TOTAL SURFACE AREA OF SYSTEM

      DO 290 J=5,110
      SAT = SAT + ASUR(J)
  290 CONTINUE
      SAT = SAT / 43560.
      WRITE(6,292) SAT
  292 FORMAT(1H ///55HTOTAL SURFACE AREA OF SAN DIEGO BAY(TO BALLAST POI
     *NT = F9.2,6H ACRES//)
  238 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PUNCH
      DIMENSION ALPHA(220),CP(840,5),CSP(840,5),VQ(840),ASUR(840),
     *    CAVE(840,5),AVOL(840)
      COMMON ALPHA,NSPEC,DELTQ,NUMCON,NALPHA,NJ,ASUR,MARK1,MARK2,KDONE,
     *    KZOP,CAVE,AVOL
      REWIND 9
      READ(9) (ALPHA(I),I=1,80)
      READ(9) (VO(J),(CP(J,K),CSP(J,K),K=1,NUMCON),J=1,NJ)
      WRITE(8,100) (ALPHA(I),I=1,80)
  100 FORMAT(20A4)
      IF(NUMCON.LT.3) GO TO 514
      NFIRST = 3
      GO TO 515
  514 NFIRST = NUMCON
  515 DO 556 J=1,NJ
      QWQ = VO(J) / DELTQ
      WRITE(8,555) J,QWQ,(CP(J,K),CSP(J,K),K=1,NFIRST)
  555 FORMAT(I5,F10.1,6F10.2)
  556 CONTINUE
      IF(NUMCON.LE.3) GO TO 517
      NFIRST = NFIRST + 1
      DO 558 J=1,NJ
      WRITE(8,557) J,(CP(J,K),CSP(J,K),K=NFIRST,NUMCON)
  557 FORMAT(I5,6F10.2)
  558 CONTINUE
  517 CONTINUE
      REWIND 9
      RETURN
      END
```

# SAMPLE JOB CONTROL LANGUAGE FOR PROGRAM DYNOUA

```
//I18012J1 JOB (807200,I0902,0015,0003,0300,1,1,,61),'FEIGNER',        X
//           CLASS=C,MSGLEVEL=1
/*SETUP    002033/9
// EXEC FORTGCLG,TIME=15,REGION.FORT=300K,REGION.GO=330K
//FORT.SYSIN DD *


**********  INSERT SOURCE DECK HERE  **********


/*
//GO.FT03F001 DD UNIT=2400,DCB=(RECFM=VBS,LRECL=504,BLKSIZE=5040),     X
//      DISP=(OLD,KEEP),LABEL=(,,,IN),DSN=SDBHX,                       X
//      VOL=SER=002033
//GO.FT09F001 DD UNIT=2314,DCB=(RECFM=VBS,LRECL=504,BLKSIZE=5040),     X
//      DISP=(NEW,KEEP),SPACE=(TRK,(20,20),RLSE),                      X
//      DSN=SYS2.D148.PUNCH,VOL=SER=TEMPAA
//GO.FT10F001 DD UNIT=SYSDK,DCB=(RECFM=VBS,LRECL=504,BLKSIZE=5040),    X
//      DISP=(NEW,DELETE),SPACE=(CYL,3),DSNAME=SDB10
//GO.SYSIN DD *


**********  INSERT DATA HERE  **********


/*
```

```
SAN DIEGO BAY HYDRAULICS WITH MEAN ANNUAL TIDE(25.0 HOUR PERIOD)
DEMONSTRATION RUN FOR DOCUMENTATION REPORT                05-27-70
QUALITY DEMONSTRATION RUN FOR DOCUMENTATION REPORT                        FEDERAL WATER QUALITY ADMINISTRATION
DYE RELEASE - BOD - DO                                                    DYNAMIC WATER QUALITY MODEL


******** FROM HYDRAULICS PROGRAM ********
START CYCLE   STOP CYCLE    TIME INTERVAL

     0           1800          50.  SECONDS



    STARTING CYCLE    INITIAL QUALITY   TOTAL QUALITY   *** OUTPUT INTERVALS ***     TIME INTERVAL IN       CONSTANT FOR
  ON HYD. EXTRACT TAPE      CYCLE           CYCLES        CYCLES         HOURS     QUALITY PROGRAM   DIFFUSION COEFFICIENTS

          0                   1              600           500           2.00        0.500 HOURS            2.500

PRINTOUT IS TO BEGIN AT CYCLE    50

QUALITY TAPE FOR EXTRACTING IS TO BEGIN AT CYCLE    50



    4 CONSTITUENTS BEING CONSIDERED IN THIS RUN


FIRST CONSTITUENT IS DYE TREATED AS A CONSERVATIVE

SECOND CONSTITUENT IS DYE WITH DECAY 0.034 PER DAY(BASE E)

THIRD CONSTITUENT IS BOD WITH 0.20 PER DAY DECAY RATE(BASE E)

FOURTH CONSTITUENT IS DISSOLVED OXYGEN WITH REOX. RATE 0.25 PER DAY(BASE E)


CONSTITUENT NO. 2 IS TREATED AS A NON-CONSERVATIVE WITH DECAY COEFFICIENT =  0.9992919 BUT IS NOT PAIRED WITH ANY OTHER CONSTITUENT


CONSTITUENT NO. 3 IS BOD WITH DECAY COEFFICIENT =  0.9958420   THE ASSOCIATED OXYGEN IS CONSTITUENT NO. 4
WITH REAERATION COEFFICIENT =      0.005194783 AND SATURATION CONCENTRATION =       8.40
```

```
                                  *****     SUMMARY OF HYDRAULIC INPUTS     *****

** JUNCTION HEAD AND HYD. RADIUS AND X-SECTIONAL AREA OF CHANNELS ARE AT MEAN TIDE **

****************************   CHANNEL DATA   **************************     **************   JUNCTION DATA   *************
CHAN.  LENGTH   WIDTH     AREA  MANNING  NET FLOW  HYD. RADIUS  JUNC. AT ENDS   JUNC.  INFLOW   HEAD  CHANNELS ENTERING JUNCTION

  1    2500.    4400.  131969.   0.015    -340.56      30.0        1     3        1      0.8    0.07     1    2    0    0    0
  2    2500.    2500.   81966.   0.015       0.0       32.8        1     2        2      0.5    0.07     2    0    0    0    0
  3    2500.    4200.  117558.   0.015    -343.78      28.0        3     4        3      1.6    0.07     1    3    0    0    0
  4    2500.    1700.   86482.   0.015    -364.31      50.9        4     5        4      1.8    0.07     3    4    0    0    0
  5    2500.    2400.  100635.   0.015    -663.24      41.9        5     6        5      1.2    0.07     4    5    6    0    0
  6    2500.    1500.   57076.   0.015     295.56      38.1        5     7        6      0.9    0.07     5    8    9    0    0
  7    2500.    1500.   54076.   0.015     294.57      36.1        7     8        7      0.5    0.07     6    7    0    0    0
  8    2500.    2350.  100881.   0.015    -504.91      42.9        6     9        8      0.6    0.07     7    9   10    0    0
  9    2350.    2200.   85619.   0.015    -160.06      38.9        6     8        9      0.9    0.07     8   11    0    0    0
 10    2500.    1250.   48809.   0.015     134.28      39.0        8    10       10      0.5    0.07    10   13   14    0    0
  •      •        •        •       •          •          •         •     •        •        •      •      •    •    •    •  - •
  •      •        •        •       •          •          •         •     •        •        •      •      •    •    •    •    •
  •      •        •        •       •          •          •         •     •        •        •      •      •    •    •    •    •
 91    2500.    1900.   24804.   0.015     508.48      13.1       68    71       91      1.1    0.07   132  135  139    0    0
 92    1800.    2100.   29517.   0.015     494.58      14.1       54    55       92      0.8    0.07   136  140    0    0    0
 93    1800.    2500.   35144.   0.015     366.91      14.1       55    69       93    646.8    0.07   140  141    0    0    0
 94    2500.    2500.   35144.   0.015     330.21      14.1       69    70       94      1.0    0.07   137  141  142  143    0
 95    2500.    2500.   33895.   0.015     281.28      13.6       70    71       95      0.9    0.07   138  139  142  144    0
 96    2250.    1650.   47936.   0.015   -3158.50      29.1       54    56       96   -645.0    0.07   145  147    0    0    0
 97    2300.    2000.   28111.   0.015     621.96      14.1       55    57       97      1.0    0.07   143  145  146  148    0
 98    2500.    2100.   29517.   0.015     449.41      14.1       69    72       98      1.0    0.07   144  146  149    0    0
 99    2500.    2500.   35144.   0.015     560.41      14.1       70    73       99      3.0    0.07   147  150  152    0    0
100    2500.    1950.   27407.   0.015     794.97      14.1       71    74      100      0.6    0.07   148  150  151    0    0
101    1850.    1700.   23891.   0.015     214.26      14.1       56    57      101      0.6    0.07   149  151    0    0    0
102    1900.    1400.   19671.   0.015     207.92      14.1       57    72      102      0.1    0.07   152  153    0    0    0
103    2500.    2500.   36394.   0.015   -1026.20      14.6       72    73      103      0.2    0.07   153    0    0    0    0
104    2500.    2500.   33894.   0.015    -782.64      13.6       73    74      104      0.2    0.07   154  155  156    0    0
105    2100.    1100.   31949.   0.015   -3020.90      29.0       56    59      105      0.2    0.07   156  157    0    0    0
106    2800.    1700.   23890.   0.015   -1472.36      14.1       59    72      106      0.2    0.07   158    0    0    0    0
107    2500.    2400.   40937.   0.015    -750.20      17.1       59    75      107      0.4    0.07   159  160    0    0    0
108    2500.    2450.   34441.   0.015     217.91      14.1       72    76      108      0.4    0.07   160  161  162    0    0
109    2500.    2500.   35144.   0.015     323.56      14.1       73    77      109      0.4    0.07   162  163  164    0    0
110    2700.     850.   11511.   0.015      17.91      13.5       74    78      110      0.5    0.07   164  165    0    0    0
111    2400.    2300.   32331.   0.015    -523.44      14.1       75    76      111      0.5   -3.01   170    0    0    0    0
112    2500.    2600.   36551.   0.015    -341.88      14.1       76    77      112      0.5   -3.01   170    0    0    0    0
113    1800.    2350.   30685.   0.015     108.69      13.1       77    78
114    2900.    2650.   39905.   0.015    -217.53      15.1       75    79
115    2800.    2000.   26112.   0.015      43.23      13.1       76    79
116    2450.    2250.   32753.   0.015    -120.54      14.6       77    80
117    2100.    1300.   16965.   0.015     129.78      13.1       78    81
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118   2800.   2500.   35145.   0.015     492.61     14.1     79   80
119   1850.   2400.   31339.   0.015     141.06     13.1     80   81
120   2400.   2700.   40659.   0.015    -657.64     15.1     79   82
121   2400.   2400.   32539.   0.015     237.48     13.6     80   83
122   2500.   1150.   15580.   0.015     274.25     13.5     81   84
123   2500.   2500.   27647.   0.015    -581.94     11.1     82   83
 •      •       •       •        •          •         •       •    •
 •      •       •       •        •          •         •       •    •
 •      •       •       •        •          •         •       •    •
159   2100.   2050.   59560.   0.015     544.43     29.1     50  107
160   2500.   1200.   15658.   0.015     547.07     13.0    107  108
161   2100.   2400.   76639.   0.015    -158.31     31.9     52  108
162   2100.   1300.   16964.   0.015     391.38     13.0    108  109
163   2100.   1200.   37255.   0.015     108.90     31.0     54  109
164   2100.   1600.   20884.   0.015     503.24     13.1    109  110
165   2100.   1100.   29749.   0.015    -506.29     27.0     56  110
166   1950.   1300.   40362.   0.015     157.71     31.0     56   58
167   2100.   1450.   18925.   0.015     159.49     13.1     58   60
168   1950.   1800.   52296.   0.015    -162.10     29.1     59   60
169   1650.   1500.   21078.   0.015     631.85     14.1     57   59
170   2500.   2500.   74937.   0.015       0.0      30.0    111  112
```

```
*****MULTIPLICATION FACTORS APPLIED TO OBTAIN STARTING CONCENTRATIONS

CONSTITUENT    GROUP    FACTOR    JUNCTION NUMBERS

     1           1       0.50          1 - 110

NO MULTIPLICATION FACTOR APPLIED TO CONSTITUENT NO. 2

NO MULTIPLICATION FACTOR APPLIED TO CONSTITUENT NO. 3

NO MULTIPLICATION FACTOR APPLIED TO CONSTITUENT NO. 4
```

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*************************************************   WATER QUALITY DATA    ***************************************************
                 * FIRST CONSTITUENT * SECOND CONSTITUENT * THIRD CONSTITUENT * FOURTH CONSTITUENT * FIFTH CONSTITUENT *
                   INITIAL    INFLOW   INITIAL     INFLOW   INITIAL    INFLOW   INITIAL     INFLOW   INITIAL     INFLOW
 JUNC.   INFLOW     CONC.      CONC.    CONC.       CONC.    CONC.      CONC.    CONC.       CONC.    CONC.       CONC.

   1      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   2      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   3      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   4      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   5      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   6      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   7      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   8      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
   9      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  10      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0

   .       .          .        .          .        .          .        .          .         .
   .       .          .        .          .        .          .        .          .         .
   .       .          .        .          .        .          .        .          .         .

  52    -18.8       0.50  1190.00       0.50  1190.00       2.00   300.00       5.00      2.00
  53      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  54      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  55      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  56      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  57      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0

   .       .          .        .          .        .          .        .          .         .
   .       .          .        .          .        .          .        .          .         .
   .       .          .        .          .        .          .        .          .         .

  92      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  93    646.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  94      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  95      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  96   -646.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  97      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  98      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
  99      2.6       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 100      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 101      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 102      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 103      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 104      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 105      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 106      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 107      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 108      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 109      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 110      0.0       0.50     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 111      0.0       1.00     0.0        0.50     0.0        2.00     0.0        5.00      0.0
 112      0.0       1.00     0.0        0.50     0.0        2.00     0.0        5.00      0.0
```

```
SPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. 1

     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500

SPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. 2

     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500      0.500      0.500      0.500      0.500      0.500      0.500
     0.500

SPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. 3

     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000      2.000      2.000      2.000      2.000      2.000      2.000
     2.000

SPECIFIED C-FACTORS AT JUNCTION 1 FOR CONSTITUENT NO. 4

     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500      7.500      7.500      7.500      7.500      7.500      7.500
     7.500
```

```
********************************************     TABLE OF WASTE WATER RETURN FACTORS     ******************************************
     JUNCTIONS USED   JUNCTIONS USED
     FOR DIVERSIONS   FOR RET. FLOWS   1ST. CONSTITUENT   2ND. CONSTITUENT   3RD. CONSTITUENT   4TH. CONSTITUENT   5TH. CONSTITUENT
UNIT  NO. 1  NO. 2     NO. 1  NO. 2    COEFF.    CONST.   COEFF.    CONST.   COEFF.    CONST.   COEFF.    CONST.   COEFF.    CONST.

 1      93     98        96     97     1.00    0.0        1.00    0.0        1.00    0.0        1.00    0.0
```

```
SYSTEM STATUS AFTER QUALITY CYCLE   50          1 DAYS,  1.00 HOURS

                              **************************  CONCENTRATION FACTORS   **************************
JUNCTION     HEAD             1ST. CONSTIT.   2ND. CONSTIT.   3RD. CONSTIT.   4TH. CONSTIT.   5TH. CONSTIT.
 NUMBER      (FT)                (MGL)           (MGL)           (MGL)           (MGL)           (MGL)

     1.     2.6020                 0.50            0.50            2.00            7.50

     2      2.6020                 0.50            0.50            2.00            7.50

     3      2.6020                 0.50            0.50            1.98            7.49

     4      2.6020                 0.50            0.50            1.97            7.49

     5      2.6362                 0.50            0.50            1.96            7.50

     6      2.6578                 0.50            0.50            1.94            7.56

    30      2.7855                 0.50            0.48            1.62            5.46

    35      2.8113                 0.50            0.48            1.62            5.45

    44      2.8849                 0.50            0.49            1.62            5.44

    52      2.9410                 2.38            2.35            2.07            5.41

    70      2.9570                 1.05            1.02            1.74            5.40

    75      2.9698                 0.81            0.78            1.68            5.41

    80      2.9789                 0.53            0.51            1.62            5.41

    90      3.0039                 0.50            0.48            1.61            5.40

   106      2.9167                 0.58            0.56            1.64            5.43

   112     -3.0000                 1.00            0.48            1.62            5.45
```

```
SYSTEM STATUS AFTER QUALITY CYCLE   98          2 DAYS,  1.00 HOURS
                                    ***************************  CONCENTRATION FACTORS  ***************************
JUNCTION       HEAD              1ST. CONSTIT.    2ND. CONSTIT.   3RD. CONSTIT.   4TH. CONSTIT.    5TH. CONSTIT.
 NUMBER        (FT)                 (MGL)            (MGL)           (MGL)           (MGL)            (MGL)

    1        2.3613                 0.50             0.50            2.00            7.50
    2        2.3613                 0.50             0.50            2.00            7.50
    3        2.3691                 0.50             0.50            1.99            7.49
    4        2.3775                 0.50             0.50            1.98            7.49
    5        2.3892                 0.50             0.50            1.98            7.50
    6        2.3968                 0.50             0.50            1.95            7.53
   30        2.4398                 0.50             0.47            1.33            5.84
   35        2.4482                 0.50             0.46            1.33            5.83
   44        2.4712                 0.52             0.49            1.33            5.83
   52        2.4881                 3.24             3.14            1.93            5.76
   70        2.4933                 1.76             1.67            1.57            5.76
   75        2.4974                 1.00             0.95            1.42            5.80
   80        2.5004                 0.63             0.59            1.35            5.81
   90        2.5085                 0.51             0.48            1.32            5.80
  106        2.4808                 0.80             0.75            1.38            5.82
  112       -3.0132                 1.00             0.47            1.33            5.84


RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE  100
HYDRAULIC CYCLE ON EXTRACT TAPE FOR RESTARTING =     0
NTAG =    0
```

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*************************    QUALITY SUMMARY    ************************
SUMMARY STARTS AT                          SUMMARY ENDS AT
CYCLE   50 (*** DAYS***** HOURS)          CYCLE  100 (  2 DAYS  2.0 HOURS)



FIRST CONSTITUENT IS DYE TREATED AS A CONSERVATIVE

SECOND CONSTITUENT IS DYE WITH DECAY 0.034 PER DAY(BASE E)

THIRD CONSTITUENT IS BOD WITH 0.20 PER DAY DECAY RATE(BASE E)

FOURTH CONSTITUENT IS DISSOLVED OXYGEN WITH REOX. RATE 0.25 PER DAY(BASE E)



         ** CONSTITUENT NO. 1 **  ** CONSTITUENT NO. 2 **  ** CONSTITUENT NO. 3 **  ** CONSTITUENT NO. 4 **  ** CONSTITUENT NO. 5 **
JUNC.      MIN.    MAX.    AVE.     MIN.    MAX.    AVE.     MIN.    MAX.    AVE.     MIN.    MAX.    AVE.     MIN.    MAX.    AVE.

  1        0.50    0.50    0.50     0.50    0.50    0.50     2.00    2.00    2.00     7.50    7.50    7.50
  2        0.50    0.50    0.50     0.50    0.50    0.50     2.00    2.00    2.00     7.50    7.50    7.50
  3        0.50    0.50    0.50     0.48    0.50    0.50     1.58    2.05    1.90     6.38    7.66    7.34
  4        0.50    0.50    0.50     0.48    0.50    0.49     1.53    2.03    1.84     5.96    7.63    7.20
  5        0.50    0.50    0.50     0.48    0.50    0.49     1.52    2.02    1.79     5.65    7.67    7.02
  6        0.50    0.50    0.50     0.47    0.50    0.49     1.48    2.01    1.72     5.43    7.70    6.79
  7        0.50    0.50    0.50     0.48    0.50    0.49     1.52    1.93    1.72     5.79    7.47    6.86
  8        0.50    0.50    0.50     0.47    0.49    0.48     1.45    1.85    1.63     5.41    7.43    6.54
  9        0.50    0.50    0.50     0.47    0.50    0.48     1.41    1.90    1.63     5.44    7.50    6.50
 10        0.50    0.50    0.50     0.47    0.49    0.48     1.39    1.77    1.57     5.40    7.27    6.28
 11        0.50    0.50    0.50     0.47    0.49    0.48     1.37    1.77    1.55     5.43    7.29    6.16
 12        0.50    0.50    0.50     0.47    0.48    0.48     1.37    1.65    1.48     5.65    6.29    5.82
 13        0.50    0.50    0.50     0.47    0.48    0.47     1.33    1.63    1.47     5.47    5.91    5.68
 14        0.50    0.50    0.50     0.47    0.48    0.47     1.32    1.62    1.47     5.45    5.87    5.66
 15        0.50    0.50    0.50     0.47    0.49    0.48     1.37    1.72    1.51     5.48    7.06    5.96
 16        0.50    0.50    0.50     0.47    0.49    0.48     1.36    1.69    1.49     5.51    6.83    5.82
 17        0.50    0.50    0.50     0.47    0.48    0.47     1.33    1.63    1.47     5.48    5.91    5.67
 18        0.50    0.50    0.50     0.47    0.48    0.47     1.32    1.62    1.47     5.45    5.85    5.66
 19        0.50    0.50    0.50     0.47    0.48    0.47     1.35    1.65    1.47     5.50    6.46    5.72
 20        0.50    0.50    0.50     0.47    0.48    0.47     1.35    1.65    1.47     5.54    6.37    5.72
 21        0.50    0.50    0.50     0.47    0.48    0.47     1.34    1.63    1.47     5.50    6.04    5.66
 22        0.50    0.50    0.50     0.47    0.48    0.47     1.32    1.62    1.46     5.48    5.89    5.65
 23        0.50    0.50    0.50     0.47    0.48    0.47     1.32    1.62    1.46     5.44    5.85    5.65
 24        0.50    0.50    0.50     0.46    0.48    0.47     1.32    1.62    1.46     5.44    5.85    5.65
 25        0.50    0.50    0.50     0.46    0.48    0.47     1.31    1.62    1.46     5.44    5.84    5.65
 26        0.50    0.50    0.50     0.46    0.48    0.47     1.31    1.62    1.46     5.44    5.84    5.65
 27        0.50    0.51    0.50     0.47    0.49    0.48     1.34    1.63    1.47     5.49    6.11    5.67
 28        0.50    0.50    0.50     0.47    0.48    0.47     1.32    1.62    1.46     5.47    5.89    5.65
```

|  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 34 | 0.50 | 0.50 | 0.50 | 0.46 | 0.48 | 0.47 | 1.31 | 1.62 | 1.46 | 5.44 | 5.84 | 5.65 |
| 35 | 0.49 | 0.68 | 0.53 | 0.46 | 0.65 | 0.50 | 1.32 | 1.62 | 1.47 | 5.45 | 5.85 | 5.65 |
| 36 | 0.50 | 0.62 | 0.52 | 0.47 | 0.60 | 0.50 | 1.32 | 1.62 | 1.47 | 5.44 | 5.84 | 5.65 |
| 37 | 0.50 | 0.64 | 0.53 | 0.47 | 0.62 | 0.50 | 1.32 | 1.62 | 1.47 | 5.44 | 5.84 | 5.65 |
| 38 | 0.50 | 1.20 | 0.64 | 0.48 | 1.16 | 0.61 | 1.32 | 1.67 | 1.49 | 5.44 | 5.84 | 5.64 |
| 39 | 0.48 | 1.29 | 0.62 | 0.46 | 1.25 | 0.59 | 1.31 | 1.69 | 1.49 | 5.44 | 5.84 | 5.64 |
| 40 | 0.50 | 2.41 | 0.86 | 0.48 | 2.35 | 0.82 | 1.32 | 1.95 | 1.54 | 5.44 | 5.84 | 5.63 |
| 41 | 0.49 | 1.29 | 0.68 | 0.46 | 1.25 | 0.64 | 1.31 | 1.70 | 1.50 | 5.44 | 5.84 | 5.64 |
| 42 | 0.44 | 2.84 | 1.07 | 0.41 | 2.77 | 1.03 | 1.32 | 2.05 | 1.59 | 5.44 | 5.84 | 5.63 |
| 43 | 0.50 | 2.46 | 0.93 | 0.48 | 2.40 | 0.90 | 1.32 | 1.97 | 1.56 | 5.44 | 5.84 | 5.63 |
| 44 | 0.45 | 3.20 | 1.29 | 0.43 | 3.13 | 1.24 | 1.32 | 2.16 | 1.63 | 5.44 | 5.84 | 5.62 |
| 45 | 0.49 | 3.32 | 1.51 | 0.47 | 3.25 | 1.46 | 1.32 | 2.20 | 1.68 | 5.43 | 5.84 | 5.61 |
| 46 | 0.51 | 2.39 | 1.28 | 0.49 | 2.32 | 1.23 | 1.32 | 1.91 | 1.62 | 5.43 | 5.84 | 5.61 |
| 47 | 0.61 | 2.41 | 1.63 | 0.59 | 2.32 | 1.57 | 1.42 | 1.80 | 1.69 | 5.42 | 5.81 | 5.59 |
| 48 | 0.46 | 3.33 | 1.77 | 0.45 | 3.23 | 1.71 | 1.33 | 2.15 | 1.74 | 5.43 | 5.83 | 5.60 |
| 49 | 0.58 | 2.43 | 1.63 | 0.56 | 2.33 | 1.56 | 1.41 | 1.88 | 1.69 | 5.41 | 5.81 | 5.59 |
| 50 | 0.32 | 3.57 | 2.14 | 0.31 | 3.48 | 2.07 | 1.32 | 2.16 | 1.82 | 5.43 | 5.82 | 5.59 |
| 51 | 0.54 | 2.73 | 1.73 | 0.52 | 2.63 | 1.66 | 1.44 | 1.86 | 1.71 | 5.41 | 5.79 | 5.59 |
| 52 | 1.73 | 4.74 | 3.39 | 1.69 | 4.64 | 3.32 | 1.83 | 2.38 | 2.12 | 5.41 | 5.77 | 5.58 |
| 53 | 0.91 | 4.06 | 2.48 | 0.87 | 3.95 | 2.41 | 1.59 | 2.13 | 1.89 | 5.39 | 5.75 | 5.58 |
| 54 | 0.41 | 4.03 | 2.08 | 0.38 | 3.92 | 2.02 | 1.48 | 2.18 | 1.81 | 5.39 | 5.74 | 5.59 |
| 55 | 0.84 | 3.81 | 2.11 | 0.81 | 3.70 | 2.05 | 1.57 | 2.14 | 1.81 | 5.38 | 5.74 | 5.59 |
| 56 | 0.62 | 2.81 | 1.37 | 0.60 | 2.72 | 1.32 | 1.46 | 1.98 | 1.65 | 5.40 | 5.77 | 5.61 |
| 57 | 0.53 | 2.94 | 1.43 | 0.50 | 2.84 | 1.38 | 1.49 | 1.99 | 1.66 | 5.38 | 5.76 | 5.60 |
| 58 | 0.78 | 1.78 | 1.11 | 0.75 | 1.71 | 1.07 | 1.47 | 1.81 | 1.59 | 5.41 | 5.79 | 5.62 |
| 59 | 0.52 | 1.86 | 0.92 | 0.49 | 1.78 | 0.89 | 1.41 | 1.81 | 1.55 | 5.41 | 5.78 | 5.62 |
| 60 | 0.64 | 1.00 | 0.77 | 0.61 | 0.94 | 0.74 | 1.41 | 1.67 | 1.52 | 5.42 | 5.81 | 5.62 |
| 61 | 0.60 | 1.99 | 1.17 | 0.57 | 1.92 | 1.12 | 1.41 | 1.80 | 1.60 | 5.42 | 5.81 | 5.61 |
| 62 | 0.70 | 1.58 | 1.21 | 0.67 | 1.51 | 1.15 | 1.49 | 1.66 | 1.60 | 5.42 | 5.79 | 5.61 |
| 63 | 0.56 | 0.91 | 0.70 | 0.54 | 0.86 | 0.67 | 1.39 | 1.63 | 1.50 | 5.43 | 5.81 | 5.63 |
| 64 | 0.50 | 0.56 | 0.52 | 0.48 | 0.53 | 0.49 | 1.32 | 1.62 | 1.46 | 5.43 | 5.83 | 5.64 |
| 65 | 0.70 | 2.39 | 1.51 | 0.67 | 2.29 | 1.45 | 1.55 | 1.81 | 1.67 | 5.40 | 5.76 | 5.59 |
| 66 | 0.79 | 3.08 | 1.89 | 0.76 | 2.96 | 1.83 | 1.57 | 1.94 | 1.76 | 5.39 | 5.75 | 5.59 |
| 67 | 0.68 | 2.36 | 1.33 | 0.66 | 2.26 | 1.27 | 1.52 | 1.79 | 1.63 | 5.40 | 5.75 | 5.60 |
| 68 | 0.64 | 1.77 | 1.03 | 0.61 | 1.68 | 0.99 | 1.47 | 1.69 | 1.56 | 5.40 | 5.77 | 5.61 |
| 69 | 0.55 | 2.90 | 1.44 | 0.52 | 2.79 | 1.39 | 1.50 | 1.93 | 1.66 | 5.39 | 5.75 | 5.60 |
| 70 | 0.52 | 1.88 | 0.95 | 0.50 | 1.79 | 0.91 | 1.43 | 1.74 | 1.55 | 5.40 | 5.77 | 5.61 |
| 71 | 0.52 | 1.32 | 0.76 | 0.50 | 1.25 | 0.72 | 1.41 | 1.65 | 1.51 | 5.41 | 5.79 | 5.62 |
| 72 | 0.53 | 2.01 | 0.96 | 0.50 | 1.93 | 0.92 | 1.41 | 1.80 | 1.55 | 5.40 | 5.77 | 5.61 |
| 73 | 0.49 | 1.20 | 0.67 | 0.47 | 1.13 | 0.63 | 1.38 | 1.66 | 1.49 | 5.41 | 5.79 | 5.62 |
| 74 | 0.50 | 0.88 | 0.59 | 0.48 | 0.82 | 0.56 | 1.37 | 1.62 | 1.47 | 5.41 | 5.80 | 5.62 |
| 75 | 0.53 | 1.08 | 0.68 | 0.50 | 1.02 | 0.65 | 1.39 | 1.68 | 1.49 | 5.41 | 5.80 | 5.62 |
| 76 | 0.51 | 1.25 | 0.69 | 0.48 | 1.19 | 0.66 | 1.38 | 1.69 | 1.50 | 5.40 | 5.79 | 5.62 |
| 77 | 0.50 | 0.88 | 0.57 | 0.47 | 0.83 | 0.54 | 1.37 | 1.64 | 1.47 | 5.41 | 5.81 | 5.62 |
| 78 | 0.49 | 0.70 | 0.53 | 0.47 | 0.66 | 0.51 | 1.34 | 1.62 | 1.46 | 5.41 | 5.81 | 5.62 |
| 79 | 0.48 | 0.82 | 0.56 | 0.46 | 0.77 | 0.53 | 1.37 | 1.64 | 1.47 | 5.41 | 5.81 | 5.62 |
| 80 | 0.49 | 0.66 | 0.52 | 0.47 | 0.62 | 0.50 | 1.33 | 1.62 | 1.46 | 5.41 | 5.81 | 5.62 |
| 81 | 0.50 | 0.58 | 0.51 | 0.47 | 0.55 | 0.48 | 1.32 | 1.61 | 1.46 | 5.41 | 5.82 | 5.62 |
| 82 | 0.49 | 0.63 | 0.52 | 0.47 | 0.59 | 0.49 | 1.33 | 1.62 | 1.46 | 5.41 | 5.81 | [illegible] |
| 83 | 0.49 | 0.55 | 0.50 | 0.47 | 0.52 | 0.48 | 1.31 | 1.61 | 1.45 | 5.40 | 5.81 | 5.61 |
| 84 | 0.49 | 0.53 | 0.50 | 0.47 | 0.49 | 0.47 | 1.30 | 1.61 | 1.45 | 5.40 | 5.82 | 5.61 |
| 85 | 0.49 | 0.55 | 0.50 | 0.47 | 0.52 | 0.48 | 1.31 | 1.61 | 1.45 | 5.40 | 5.81 | 5.61 |
| 86 | 0.49 | 0.51 | 0.50 | 0.46 | 0.48 | 0.47 | 1.29 | 1.61 | 1.45 | 5.39 | 5.81 | 5.61 |

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 .       .     .     .      .     .     .      .     .     .      .     .     .
 .       .     .     .      .     .     .      .     .     .      .     .     .
 .       .     .     .      .     .     .      .     .     .      .     .     .
 95     0.49  0.50  0.49   0.46  0.48  0.47   1.29  1.61  1.45   5.39  5.81  5.60
 96     0.48  0.49  0.49   0.45  0.47  0.47   1.27  1.60  1.44   5.35  5.78  5.58
 97     0.48  0.49  0.49   0.45  0.47  0.47   1.28  1.60  1.44   5.36  5.79  5.58
 98     0.49  0.49  0.49   0.45  0.48  0.47   1.28  1.60  1.44   5.37  5.80  5.59
 99     0.48  0.49  0.49   0.45  0.47  0.46   1.27  1.59  1.44   5.35  5.77  5.57
100     0.48  0.49  0.49   0.45  0.47  0.46   1.27  1.60  1.44   5.35  5.78  5.57
101     0.48  0.49  0.49   0.45  0.47  0.47   1.28  1.60  1.44   5.36  5.78  5.58
102     0.48  0.49  0.49   0.45  0.47  0.46   1.27  1.59  1.44   5.35  5.77  5.57
103     0.48  0.49  0.49   0.45  0.47  0.46   1.27  1.59  1.43   5.34  5.76  5.56
104     0.33  2.99  1.31   0.31  2.93  1.27   1.31  2.11  1.64   5.43  5.84  5.62
105     0.49  3.10  1.66   0.47  3.02  1.61   1.34  2.12  1.71   5.42  5.83  5.61
106     0.52  0.80  0.65   0.50  0.75  0.62   1.37  1.64  1.49   5.43  5.82  5.64
107     0.76  2.40  1.47   0.73  2.30  1.41   1.57  1.74  1.66   5.41  5.77  5.60
108     1.00  2.32  1.41   0.97  2.22  1.35   1.53  1.80  1.65   5.41  5.76  5.60
109     0.92  1.82  1.19   0.88  1.74  1.14   1.52  1.73  1.60   5.41  5.78  5.61
110     0.60  1.19  0.92   0.58  1.12  0.88   1.44  1.65  1.54   5.42  5.80  5.62
111     1.00  1.00  1.00   0.47  0.48  0.47   1.32  1.62  1.47   5.45  5.86  5.66
112     1.00  1.00  1.00   0.47  0.48  0.47   1.32  1.62  1.47   5.45  5.86  5.66


AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 1 =      0.7 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 2 =      1.3 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 3 =      1.3 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 4 =      0.5 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 5 =      0.5 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 6 =      1.1 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN TOTAL BAY =      0.8 MG/L.




AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 1 =      0.7 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 2 =      1.2 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 3 =      1.2 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 4 =      0.5 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 5 =      0.5 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 6 =      1.0 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN TOTAL BAY =      0.8 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 1 =       1.5 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 2 =       1.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 3 =       1.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 4 =       1.5 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 5 =       1.7 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 6 =       1.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN TOTAL BAY =       1.6 MG/L.


AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 1 =       5.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 2 =       5.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 3 =       5.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 4 =       5.8 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 5 =       6.8 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 6 =       5.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN TOTAL BAY =       5.8 MG/L.

MEAN VOLUME OF ZONE NO. 1 = 0.250401050E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 2 = 0.224610608E 09 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 3 = 0.280840986E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 4 = 0.300359552E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 5 = 0.108537216E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 6 = 0.804166400E 08 CUBIC FEET.
MEAN VOLUME OF TOTAL BAY = 0.970626253E 10 CUBIC FEET.

TOTAL SURFACE AREA OF SAN DIEGO BAY(TO BALLAST POINT =  10714.41 ACRES
SYSTEM STATUS AFTER QUALITY CYCLE  550          11 DAYS, 11.00 HOURS

                               ***************************  CONCENTRATION FACTORS   ***************************
JUNCTION     HEAD           1ST. CONSTIT.   2ND. CONSTIT.   3RD. CONSTIT.   4TH. CONSTIT.   5TH. CONSTIT.
 NUMBER      (FT)              (MGL)           (MGL)           (MGL)           (MGL)           (MGL)

     1      2.6020             0.50            0.50            2.00            7.50
     2      2.6020             0.50            0.50            2.00            7.50
     3      2.6020             0.50            0.50            1.98            7.50
     4      2.6020             0.50            0.50            1.97            7.49
     5      2.6362             0.50            0.50            1.97            7.49
     6      2.6578             0.50            0.50            1.97            7.47
    30      2.7855             0.94            0.68            0.30            7.76
    35      2.8113             1.10            0.80            0.27            7.76
    44      2.8849             2.02            1.54            0.30            7.69
    52      2.9410             6.99            6.07            1.12            7.42
    70      2.9570             6.43            5.37            0.85            7.31
    75      2.9698             4.35            3.50            0.55            7.42
    80      2.9789             4.00            3.14            0.46            7.41
    90      3.0039             2.07            1.56            0.28            7.48
   106      2.9167             4.09            3.24            0.49            7.52
   112     -3.0000             1.00            0.34            0.20            7.85
```

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SYSTEM STATUS AFTER QUALITY CYCLE  599          12 DAYS, 11.50 HOURS

                              **************************   CONCENTRATION FACTORS    **************************
JUNCTION      HEAD           1ST. CONSTIT.    2ND. CONSTIT.    3RD. CONSTIT.    4TH. CONSTIT.    5TH. CONSTIT.
 NUMBER       (FT)              (MGL)            (MGL)            (MGL)            (MGL)            (MGL)

      1      2.5409             0.50             0.50             2.00             7.50

      2      2.5409             0.50             0.50             2.00             7.50

      3      2.5530             0.50             0.50             1.98             7.49

      4      2.5662             0.50             0.50             1.97             7.49

      5      2.5845             0.50             0.50             1.97             7.49

      6      2.5961             0.50             0.50             1.98             7.47

     30      2.6631             1.06             0.75             0.26             7.84

     35      2.6764             1.25             0.89             0.24             7.84

     44      2.7134             2.26             1.69             0.28             7.78

     52      2.7407             7.33             6.28             1.08             7.51

     70      2.7487             6.81             5.61             0.82             7.42

     75      2.7553             4.69             3.71             0.52             7.54

     80      2.7600             4.35             3.36             0.43             7.53

     90      2.7728             2.31             1.70             0.25             7.62

    106      2.7289             4.48             3.49             0.47             7.61

    112     -3.0135             1.00             0.33             0.16             7.94



RESTART DECK TAPE WAS LAST WRITTEN AFTER CYCLE  600
HYDRAULIC CYCLE ON EXTRACT TAPE FOR RESTARTING =      0
NTAG =    0
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SYSTEM STATUS AFTER QUALITY CYCLE  600          12 DAYS, 12.00 HOURS

                          *************************  CONCENTRATION FACTORS  ***************************
JUNCTION     HEAD         1ST. CONSTIT.   2ND. CONSTIT.   3RD. CONSTIT.   4TH. CONSTIT.   5TH. CONSTIT.
 NUMBER      (FT)            (MGL)           (MGL)           (MGL)           (MGL)           (MGL)

    1       2.6020           0.50            0.50            2.00            7.50
    2       2.6020           0.50            0.50            2.00            7.50
    3       2.6020           0.50            0.50            1.98            7.50
    4       2.6020           0.50            0.50            1.97            7.49
    5       2.6362           0.50            0.50            1.97            7.49
    6       2.6578           0.50            0.50            1.98            7.47
   30       2.7855           1.05            0.74            0.27            7.83
   35       2.8113           1.23            0.87            0.24            7.84
   44       2.8849           2.22            1.66            0.27            7.77
   52       2.9410           7.31            6.27            1.09            7.49
   70       2.9570           6.81            5.61            0.82            7.38
   75       2.9698           4.70            3.72            0.52            7.49
   80       2.9789           4.36            3.37            0.43            7.48
   90       3.0039           2.33            1.72            0.25            7.55
  106       2.9167           4.46            3.48            0.46            7.60
  112      -3.0000           1.00            0.33            0.16            7.94
```

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*************************     QUALITY SUMMARY     ************************
SUMMARY STARTS AT                          SUMMARY ENDS AT
CYCLE  550 (*** DAYS***** HOURS)           CYCLE  600 ( 12 DAYS 12.0 HOURS)



FIRST CONSTITUENT IS DYE TREATED AS A CONSERVATIVE

SECOND CONSTITUENT IS DYE WITH DECAY 0.034 PER DAY(BASE F)

THIRD CONSTITUENT IS BOD WITH 0.20 PER DAY DECAY RATE(BASE F)

FOURTH CONSTITUENT IS DISSOLVED OXYGEN WITH REOX. RATE 0.25 PER DAY(BASE E)



         ** CONSTITUENT NO. 1 **  ** CONSTITUENT NO. 2 **  ** CONSTITUENT NO. 3 **  ** CONSTITUENT NO. 4 **  ** CONSTITUENT NO. 5 **
JUNC.       MIN.    MAX.    AVE.     MIN.    MAX.    AVE.     MIN.    MAX.    AVE.     MIN.    MAX.    AVE.     MIN.    MAX.    AVE.


  1         0.50    0.50    0.50     0.50    0.50    0.50     2.00    2.00    2.00     7.50    7.50    7.50
  2         0.50    0.50    0.50     0.50    0.50    0.50     2.00    2.00    2.00     7.50    7.50    7.50
  3         0.49    0.54    0.50     0.46    0.50    0.49     1.09    2.12    1.84     7.43    7.52    7.48
  4         0.49    0.59    0.51     0.46    0.50    0.49     0.78    2.09    1.72     7.43    7.60    7.49
  5         0.49    0.69    0.53     0.46    0.52    0.49     0.50    2.10    1.57     7.43    7.70    7.51
  6         0.48    0.89    0.57     0.45    0.63    0.50     0.22    2.12    1.35     7.44    7.80    7.54
  7         0.50    0.68    0.54     0.46    0.51    0.48     0.58    1.92    1.41     7.44    7.67    7.52
  8         0.50    0.90    0.59     0.45    0.63    0.50     0.21    1.83    1.13     7.44    7.80    7.57
  9         0.48    1.08    0.63     0.46    0.77    0.52     0.21    1.94    1.09     7.44    7.81    7.59
 10         0.50    1.09    0.65     0.46    0.78    0.52     0.20    1.66    0.90     7.45    7.81    7.62
 11         0.50    1.28    0.73     0.46    0.93    0.57     0.20    1.67    0.79     7.44    7.81    7.65
 12         0.55    0.67    0.62     0.40    0.49    0.46     0.39    0.74    0.50     7.64    7.79    7.74
 13         0.56    0.59    0.57     0.39    0.41    0.40     0.29    0.35    0.31     7.78    7.85    7.83
 14         0.52    0.54    0.53     0.36    0.37    0.36     0.22    0.26    0.24     7.83    7.91    7.88
 15         0.51    1.41    0.83     0.45    1.03    0.62     0.22    1.44    0.60     7.47    7.83    7.69
 16         0.51    1.55    0.93     0.45    1.14    0.69     0.22    1.25    0.46     7.49    7.84    7.73
 17         0.66    0.78    0.74     0.47    0.54    0.52     0.25    0.33    0.27     7.77    7.86    7.82
 18         0.58    0.62    0.60     0.40    0.42    0.41     0.20    0.23    0.21     7.81    7.90    7.86
 19         0.54    1.86    1.11     0.44    1.39    0.81     0.22    0.91    0.35     7.57    7.84    7.76
 20         0.57    1.33    0.97     0.46    0.97    0.70     0.23    0.83    0.35     7.60    7.84    7.77
 21         0.71    1.45    1.15     0.53    1.06    0.83     0.22    0.50    0.27     7.69    7.84    7.80
 22         0.78    1.07    0.95     0.54    0.77    0.67     0.20    0.32    0.23     7.75    7.87    7.83
 23         0.71    0.84    0.77     0.49    0.58    0.53     0.18    0.22    0.20     7.80    7.89    7.86
 24         0.59    0.63    0.60     0.40    0.42    0.41     0.17    0.21    0.19     7.82    7.91    7.87
 25         0.75    0.88    0.81     0.52    0.61    0.56     0.19    0.22    0.20     7.79    7.89    7.84
 26         0.63    0.70    0.66     0.43    0.47    0.45     0.17    0.21    0.19     7.80    7.90    7.85
 27         0.63    2.14    1.32     0.48    1.63    0.97     0.22    0.58    0.29     7.67    7.84    7.78
 28         0.91    1.63    1.30     0.66    1.20    0.94     0.22    0.32    0.24     7.75    7.85    7.80
 ⋮       ⋮     ⋮     ⋮     ⋮     ⋮     ⋮     ⋮     ⋮     ⋮     ⋮     ⋮     ⋮
34     1.04  1.21  1.12  0.74  0.85  0.79  0.20  0.22  0.21  7.76  7.86  7.81
35     1.10  3.72  2.08  0.60  2.98  1.58  0.23  0.48  0.30  7.59  7.84  7.74
36     1.41  3.45  2.09  1.06  2.74  1.58  0.23  0.45  0.29  7.60  7.84  7.74
37     1.59  3.30  2.32  1.19  2.62  1.77  0.24  0.44  0.31  7.62  7.82  7.72
38     1.68  5.57  2.94  1.26  4.62  2.31  0.25  0.74  0.39  7.46  7.81  7.67
39     1.41  5.94  2.79  1.04  4.95  2.18  0.23  0.79  0.37  7.46  7.83  7.69
40     1.73  7.81  3.67  1.30  6.70  2.95  0.25  1.14  0.49  7.35  7.81  7.63
41     1.63  5.52  3.13  1.22  4.59  2.47  0.24  0.76  0.41  7.48  7.82  7.66
42     1.79  8.25  4.26  1.35  7.12  3.48  0.25  1.22  0.57  7.33  7.80  7.59
43     2.07  7.61  4.00  1.59  6.53  3.24  0.28  1.12  0.53  7.37  7.78  7.60
44     2.02  8.76  4.86  1.54  7.63  4.01  0.27  1.35  0.66  7.31  7.78  7.55
45     2.45  8.92  5.54  1.90  7.78  4.60  0.31  1.39  0.75  7.30  7.74  7.50
46     2.46  7.73  5.54  1.91  6.64  4.58  0.32  1.11  0.72  7.34  7.74  7.48
47     4.30  7.85  6.66  3.50  6.64  5.57  0.53  1.05  0.87  7.30  7.61  7.40
48     2.96  8.49  6.10  2.33  7.38  5.11  0.37  1.31  0.83  7.31  7.69  7.46
49     4.46  7.69  6.68  3.64  6.55  5.58  0.56  1.08  0.87  7.32  7.59  7.39
50     3.61  8.60  6.80  2.86  7.43  5.75  0.42  1.30  0.95  7.32  7.63  7.42
51     4.97  7.81  6.82  4.08  6.60  5.70  0.61  1.06  0.89  7.31  7.53  7.38
52     5.95  9.59  8.11  4.98  8.39  7.03  0.83  1.52  1.25  7.33  7.51  7.39
53     5.78  8.98  7.45  4.71  7.78  6.33  0.65  1.35  1.05  7.31  7.44  7.37
54     3.72  8.74  6.42  2.87  7.57  5.38  0.39  1.32  0.88  7.33  7.49  7.42
55     4.98  8.56  6.70  4.00  7.37  5.63  0.59  1.28  0.92  7.30  7.44  7.40
56     3.55  7.45  5.27  2.76  6.29  4.31  0.41  1.03  0.67  7.35  7.52  7.46
57     3.87  7.48  5.57  3.01  6.33  4.57  0.43  1.05  0.71  7.32  7.49  7.43
58     4.24  5.89  4.87  3.36  4.82  3.93  0.49  0.75  0.59  7.39  7.52  7.48
59     3.07  6.09  4.46  2.35  4.99  3.55  0.35  0.78  0.52  7.38  7.54  7.48
60     3.93  4.59  4.24  3.08  3.61  3.34  0.45  0.53  0.48  7.45  7.55  7.50
61     3.89  6.96  5.30  3.15  5.88  4.34  0.50  0.96  0.67  7.39  7.63  7.50
62     5.42  6.50  6.09  4.47  5.37  5.03  0.68  0.82  0.76  7.36  7.51  7.43
63     4.63  5.18  4.91  3.67  4.11  3.90  0.52  0.58  0.55  7.45  7.55  7.50
64     3.07  3.56  3.27  2.32  2.68  2.46  0.34  0.38  0.35  7.57  7.67  7.63
65     5.99  7.46  6.80  4.88  6.31  5.65  0.70  1.01  0.86  7.31  7.46  7.36
66     5.46  8.01  6.90  4.42  6.80  5.78  0.64  1.11  0.91  7.30  7.42  7.37
67     5.49  7.37  6.46  4.43  6.15  5.33  0.63  0.96  0.80  7.30  7.42  7.37
68     5.81  6.90  6.33  4.70  5.67  5.17  0.66  0.84  0.74  7.30  7.42  7.37
69     4.46  7.69  6.07  3.52  6.49  5.00  0.49  1.06  0.76  7.30  7.45  7.40
70     4.54  6.81  5.71  3.57  5.61  4.62  0.49  0.85  0.66  7.31  7.45  7.40
71     5.04  6.45  5.75  3.99  5.22  4.62  0.54  0.74  0.64  7.31  7.44  7.39
72     3.58  6.58  5.07  2.77  5.43  4.08  0.40  0.84  0.59  7.33  7.49  7.44
73     3.50  5.98  4.83  2.69  4.81  3.82  0.38  0.64  0.52  7.34  7.50  7.44
74     4.37  5.84  5.13  3.40  4.64  4.05  0.46  0.62  0.54  7.34  7.47  7.42
75     2.64  4.70  3.68  2.00  3.72  2.87  0.31  0.55  0.42  7.42  7.56  7.51
76     2.72  5.50  4.15  2.06  4.41  3.26  0.32  0.64  0.46  7.37  7.54  7.48
77     2.76  5.28  4.05  2.08  4.17  3.14  0.31  0.57  0.43  7.37  7.54  7.48
78     3.36  5.19  4.27  2.55  4.06  3.31  0.35  0.54  0.44  7.37  7.52  7.46
79     1.65  4.29  3.06  1.20  3.34  2.34  0.23  0.48  0.34  7.43  7.58  7.53
80     2.06  4.36  3.21  1.53  3.37  2.45  0.26  0.46  0.35  7.41  7.57  7.51
81     3.00  4.58  3.77  2.26  3.53  2.89  0.32  0.46  0.38  7.40  7.54  7.48
82     1.28  3.56  2.45  0.92  2.72  1.84  0.21  0.39  0.29  7.45  7.60  7.54
83     1.52  3.65  2.56  1.11  2.77  1.92  0.22  0.38  0.29  7.43  7.59  7.53
84     2.40  3.96  3.21  1.79  3.00  2.42  0.28  0.40  0.33  7.41  7.56  7.50
85     1.07  3.04  1.97  0.76  2.28  1.46  0.19  0.34  0.25  7.47  7.61  7.55
86     1.32  3.10  2.05  0.95  2.31  1.51  0.21  0.33  0.25  7.43  7.60  7.54
87     1.74  3.49  2.63  1.27  2.62  1.96  0.24  0.35  0.29  7.39  7.58  7.51
88     1.18  2.10  1.51  0.85  1.54  1.09  0.19  0.26  0.22  7.49  7.62  7.55
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  ⋮       ⋮      ⋮      ⋮       ⋮      ⋮      ⋮       ⋮      ⋮      ⋮       ⋮      ⋮      ⋮
 95     0.71   1.81   1.20    0.49   1.31   0.85    0.17   0.24   0.20    7.46   7.63   7.54
 96     0.79   0.91   0.85    0.55   0.63   0.59    0.16   0.19   0.17    7.41   7.60   7.51
 97     0.71   1.04   0.83    0.49   0.73   0.58    0.16   0.20   0.17    7.43   7.61   7.51
 98     0.73   1.32   0.97    0.51   0.94   0.68    0.17   0.21   0.18    7.45   7.63   7.52
 99     0.68   0.79   0.73    0.47   0.54   0.50    0.15   0.18   0.17    7.39   7.58   7.49
100     0.67   0.83   0.73    0.46   0.56   0.50    0.15   0.18   0.17    7.40   7.59   7.49
101     0.67   0.95   0.78    0.46   0.65   0.54    0.16   0.19   0.17    7.41   7.60   7.50
102     0.54   0.77   0.68    0.37   0.53   0.47    0.15   0.18   0.16    7.39   7.58   7.48
103     0.59   0.68   0.63    0.40   0.46   0.43    0.15   0.18   0.16    7.37   7.56   7.46
104     2.13   8.33   5.05    1.62   7.23   4.17    0.28   1.28   0.68    7.32   7.77   7.53
105     3.09   8.58   5.88    2.44   7.41   4.91    0.38   1.29   0.80    7.31   7.69   7.48
106     4.00   4.49   4.23    3.11   3.50   3.31    0.44   0.49   0.47    7.52   7.61   7.57
107     6.17   7.42   6.66    5.11   6.72   5.54    0.75   0.96   0.84    7.35   7.46   7.38
108     6.26   7.32   6.64    5.14   6.11   5.50    0.74   0.95   0.83    7.33   7.42   7.38
109     5.67   6.90   6.30    4.61   5.68   5.17    0.68   0.85   0.76    7.32   7.43   7.39
110     4.97   6.22   5.71    3.99   5.02   4.62    0.58   0.72   0.66    7.34   7.46   7.42
111     1.00   1.00   1.00    0.33   0.34   0.33    0.16   0.20   0.18    7.85   7.94   7.90
112     1.00   1.00   1.00    0.33   0.34   0.33    0.16   0.20   0.18    7.85   7.94   7.90


AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 1 =       3.7 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 2 =       6.3 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 3 =       4.5 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 4 =       1.1 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 5 =       0.6 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN ZONE NO. 6 =       4.9 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 1 IN TOTAL BAY =       2.9 MG/L.



AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 1 =       2.9 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 2 =       5.2 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 3 =       3.7 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 4 =       0.8 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 5 =       0.5 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN ZONE NO. 6 =       3.9 MG/L.

AVERAGE CONCENTRATION OF CONSTITUENT NO. 2 IN TOTAL BAY =       2.3 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 1 =        0.4 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 2 =        0.8 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 3 =        0.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 4 =        0.4 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 5 =        1.3 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN ZONE NO. 6 =        0.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 3 IN TOTAL BAY =        0.6 MG/L.



AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 1 =        7.5 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 2 =        7.4 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 3 =        7.6 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 4 =        7.8 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 5 =        7.5 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN ZONE NO. 6 =        7.5 MG/L.
AVERAGE CONCENTRATION OF CONSTITUENT NO. 4 IN TOTAL BAY =        7.6 MG/L.

MEAN VOLUME OF ZONE NO. 1 = 0.250401050E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 2 = 0.224610608E 09 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 3 = 0.280840986E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 4 = 0.300359552E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 5 = 0.108537216E 10 CUBIC FEET.
MEAN VOLUME OF ZONE NO. 6 = 0.804166400E 08 CUBIC FEET.
MEAN VOLUME OF TOTAL BAY = 0.970626253E 10 CUBIC FEET.


TOTAL SURFACE AREA OF SAN DIEGO BAY(TO BALLAST POINT =  10714.41 ACRES


END OF QUALITY RUN.  600  CYCLES.
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## PROGRAM REGAN

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C                FEDERAL WATER QUALITY ADMINISTRATION
C
CURVE FITTING BY LEAST SQUARES *** Y(T)= A(1)+ A2*SIN(WT)+ A3*SIN(2WT)+
C     A4*SIN(3WT)+ A5*COS(WT)+ A6*COS(2WT)+ A7*COS(3WT)
C     NI= NO. OF POINTS        NJ= NO. OF TERMS
C
      DIMENSION Y(100), T(100), A(20), X(20), SXX(20,20), SXY(20)
    1 READ (5,10) KO,NI,NJ,MAXIT,DELTA,PERIOD,ALAG,BLAG
   10 FORMAT (4I3, 4F12.6 )
      READ(5,20) (T(I),Y(I),I=1,NI)
   20 FORMAT (8F8.3 )
      W = 2.*3.14159 /PERIOD
      WRITE (6,11) NI,NJ,PERIOD,W,ALAG,BLAG
   11 FORMAT ( 14H1NO. OF POINTS , I4 / 14H NO. OF TERMS , I4 / 7H PERIO
     1D , F8.3 , 5X, 6H OMEGA , F10.4 / 5H ALAG , F10.4, 5H BLAG ,F10.4)
      WRITE (6,21)
   21 FORMAT ( 29H0 NO.       TIME        VALUE   )
      WRITE (6,22) (I,T(I),Y(I),I=1,NI)
   22 FORMAT ( I4, 2F12.3 )
      DO 27 I=1,NI
   27 T(I) = T(I) + ALAG
C
CCC     * * *   NORMAL  EQUATIONS   * * * *
C
      DO 30 J =1,NJ
      DO 26 K=1,NJ
   26 SXX(K,J) = 0.
      A(J) = 0.
   30 SXY(J) = 0.
      NJ2 = NJ/2 + 1
      DO 50 I = 1,NI
      DO 49 J =1,NJ
      FJ1 = FLOAT(J-1)
      FJ3 = FLOAT ( J-NJ2 )
      IF ( J.LE.NJ2 ) GO TO 48
      X(J) = COS(FJ3*W*T(I)+ BLAG )
      GO TO 49
   48 X(J) = SIN(FJ1*W*T(I)+ BLAG )
      IF( J.EQ.1 ) X(J) = 1.
   49 SXY(J) = SXY(J) + X(J) * Y(I)
      DO 45 J = 1,NJ
      DO 45 K = 1, NJ
   45 SXX(K,J) = SXX(K,J) + X(K) * X(J)
   50 CONTINUE
      WRITE (6,59)
   59 FORMAT ( 42H0  J   SIGMA XY(J)   SIGMA XX(K,J), K=1,NJ  )
      DO 60 J = 1,NJ
   60 WRITE (6,62) J,SXY(J),(SXX(K,J),K=1,NJ)
   62 FORMAT ( I4, 8F14.6 )
C
CCC     * * * *   NORMAL  EQUATION  SOLUTION   * * * *
C
      IT = 0
  105 IT = IT + 1
      DELMAX = 0.
      DO 115 K =1,NJ
      SUM = 0.
      DO 110 J=1,NJ
      IF (J.EQ.K) GO TO 110
      SUM = SUM - A(J)*SXX(K,J)
  110 CONTINUE
      SUM = (SUM+SXY(K))/SXX(K,K)
      DEL = ABS(SUM-A(K))
      IF (DEL.GT.DELMAX ) DELMAX = DEL
  115 A(K) = SUM
      IF ( IT.GE.MAXIT ) GO TO 150
      IF (DELMAX.GT.DELTA ) GO TO 105
  150 WRITE(6,158) IT,DELMAX
  158 FORMAT (12HOITERATIONS ,I4,5X, 13HMAX. RESIDUAL , F12.6 )
      WRITE (6,160) (A(K),K=1,NJ)
  160 FORMAT  ( 28HOCOEFFICIENTS  A(J)  J=1,NJ  / 8F14.6 )
      WRITE (6,168)
      RES = 0.
      DO 170 I = 1,NI
      SUM = 0.
      DO 167 J =2,NJ
      FJ1 = FLOAT ( J-1 )
      FJ3 = FLOAT ( J-NJ2 )
      IF ( J.LE.NJ2 ) GO TO 166
      SUM = SUM + A(J) *COS(FJ3*W*T(I) + BLAG )
      GO TO 167
  166 SUM = SUM + A(J) *SIN(FJ1*W*T(I) + BLAG )
  167 CONTINUE
      SUM = SUM + A(1)
      DIFF = SUM - Y(I)
      RES = RES + ABS(DIFF)
  170 WRITE (6,169) T(I),Y(I),SUM,DIFF
  168 FORMAT ( 46HO        TIME    OBSERVED    COMPUTED       DIFF   )
  169 FORMAT ( 4F12.4 )
      WRITE (6,171) RES
  171 FORMAT ( 6HOTOTAL , 30X, F12.4 )
      IF ( KO.EQ.1 ) GO TO 1
 1943  STOP
      END
```

```
NO. OF POINTS  51
NO. OF TERMS    7
PERIOD  25.000        OMEGA     0.2513
ALAG     0.0     BLAG     0.0

 NO.       TIME          VALUE
  1         0.0          2.600
  2         0.500        2.540
  3         1.000        2.350
  4         1.500        2.050
  5         2.000        1.640
  6         2.500        1.160
  7         3.000        0.610
  8         3.500        0.040
  9         4.000       -0.530
 10         4.500       -1.080
 11         5.000       -1.580
 12         5.500       -2.010
 13         6.000       -2.340
 14         6.500       -2.570
 15         7.000       -2.680
 16         7.500       -2.670
 17         8.000       -2.550
 18         8.500       -2.320
 19         9.000       -1.990
 20         9.500       -1.590
 21        10.000       -1.140
 22        10.500       -0.650
 23        11.000       -0.170
 24        11.500        0.290
 25        12.000        0.690
 26        12.500        1.010
 27        13.000        1.250
 28        13.500        1.370
 29        14.000        1.390
 30        14.500        1.300
 31        15.000        1.120
 32        15.500        0.860
 33        16.000        0.540
 34        16.500        0.200
 35        17.000       -0.140
 36        17.500       -0.440
  .          .              .
  .          .              .
  .          .              .
 48        23.500        2.080
 49        24.000        2.360
 50        24.500        2.540
 51        25.000        2.600

  J    SIGMA XY(J)    SIGMA XX(K,J), K=1,NJ
  1      6.000006      51.000000     -0.000021      -0.000024      -0.000037       0.999934       0.999937       0.999909
  2    -21.968155      -0.000021     24.999908       0.000001      -0.000009      -0.000017       0.000006       0.000019
 3    13.977745    -0.000024     0.000001    24.999847    -0.000007    -0.000027    -0.000018     0.000030
 4    -2.059213    -0.000037    -0.000009    -0.000007    24.999847    -0.000045    -0.000054    -0.000028
 5    21.818253     0.999934    -0.000017    -0.000027    -0.000045    25.999802     0.999936     0.999915
 6    46.103821     0.999937     0.000006    -0.000018    -0.000054     0.999936    25.999817     0.999927
 7     3.233039     0.999909     0.000019     0.000030    -0.000028     0.999915     0.999927    25.999832

ITERATIONS    5    MAX. RESIDUAL    0.000000

COEFFICIENTS  A(J)  J=1,NJ
    0.067964    -0.878729     0.559115    -0.082364     0.768662     1.740088     0.025251

     TIME     OBSERVED    COMPUTED      DIFF
    0.0         2.6000      2.6020     0.0020
    0.5000      2.5400      2.5381    -0.0019
    1.0000      2.3500      2.3502     0.0002
    1.5000      2.0500      2.0466    -0.0034
    2.0000      1.6400      1.6421     0.0021
    2.5000      1.1600      1.1567    -0.0033
    3.0000      0.6100      0.6145     0.0045
    3.5000      0.0400      0.0422     0.0022
      •           •           •          •
      •           •           •          •
      •           •           •          •
   11.5000      0.2900      0.2856    -0.0044
   12.0000      0.6900      0.6878    -0.0022
   12.5000      1.0100      1.0141     0.0041
   13.0000      1.2500      1.2468    -0.0032
   13.5000      1.3700      1.3742     0.0042
   14.0000      1.3900      1.3917     0.0017
   14.5000      1.3000      1.3028     0.0028
   15.0000      1.1200      1.1182    -0.0018
   15.5000      0.8600      0.8560    -0.0040
   16.0000      0.5400      0.5400     0.0000
   16.5000      0.2000      0.1984    -0.0016
   17.0000     -0.1400     -0.1386     0.0014
   17.5000     -0.4400     -0.4409    -0.0009
   18.0000     -0.6800     -0.6810    -0.0010
   18.5000     -0.8400     -0.8358     0.0042
   19.0000     -0.8900     -0.8889     0.0011
   19.5000     -0.8300     -0.8316    -0.0016
   20.0000     -0.6600     -0.6640    -0.0040
   20.5000     -0.4000     -0.3946     0.0054
   21.0000     -0.0400     -0.0398     0.0002
   21.5000      0.3800      0.3773    -0.0027
   22.0000      0.8300      0.8284    -0.0016
   22.5000      1.280C      1.2828     0.0028
   23.0000      1.7100      1.7089    -0.0011
   23.5000      2.0800      2.0771    -0.0029
   24.0000      2.3600      2.3613     0.0013
   24.5000      2.5400      2.5409     0.0009
   25.0000      2.6000      2.6020     0.0020

TOTAL                                  0.1116
```

# PROGRAM DATAP

```
C                FEDERAL WATER QUALITY ADMINISTRATION
C                       DATA PREPARATION PROGRAM
C                           PROGRAM DATAP
C
C
      DIMENSION QIN( 840),ASUR( 840),Y( 840),QINEV( 840),QINPR(  840),
     *  NCHAN( 840,5),ALPHA(40)
C
C***** READ INPUT DATA
C
      READ(5,100) (ALPHA(I),I=1,40)
  100 FORMAT( 20A4)
C
      READ(5,102) NJ,MONTH
  102 FORMAT(3I5)
C
      DO 108 J=1,NJ
      READ(5,233)JJ,Y(J),ASUR(J),QIN(J),(NCHAN(J,K),K=1,5)
      QIN(J) = 0.0
      IF(JJ - J)104,108,104
  104 WRITE(6,106) JJ,J
  106 FORMAT(33H0 DATA CARD OUT OF SEQUENCE JJ = I5,4H J= I5)
      CALL EXIT
  108 CONTINUE
C
      WRITE(6,110) (ALPHA(I),I=1,40)
  110 FORMAT(1H1////1H 20A4,10X,37H FEDERAL WATER QUALITY ADMINISTRATION
     */1H 20A4,10X,25H DATA PREPARATION PROGRAM////)
      READ(5,170) EVAP,PRECIP
  170 FORMAT(2F10.0)
C
      WRITE(6,172) MONTH,EVAP,PRECIP
  172 FORMAT(9H0MONTH = I3//
     *       15H EVAPORATION = F8.2,7H INCHES//
     *       17H PRECIPITATION = F8.2,7H INCHES//)
C
C***** DETERMINE NUMBER OF DAYS IN MONTH BEING CONSIDERED
C
      IF(MONTH.NE.2)GO TO 178
      DAYS = 28.
      GO TO 184
  178 IF(MONTH.EQ.4.OR.MONTH.EQ.6.OR.MONTH.EQ.9.OR.MONTH.EQ.11)GO TO 180
      DAYS = 31.
      GO TO 184
  180 DAYS = 30.
  184 CONTINUE
C
C***** CONVERT EVAP AND PRECIP TO FEET PER SECOND
C
      CONVRT = (1./(12.* 3600. * 24. * DAYS))
      EVAP = EVAP * CONVRT
      PRECIP = PRECIP * CONVRT
C
C***** COMPUTE EVAP AND PRECIP AT EACH JUNCTION
C
      DO 188 J=1,NJ
      QINEV(J) = ASUR(J) * EVAP
      QINPR (J) = ASUR(J) * PRECIP
  188 CONTINUE
C
C      READ HYDRAULIC INPUTS AT SPECIFIED JUNCTIONS
C
      READ(5,102) NJREAD
      DO 222 I=1,NJREAD
      READ(5,220) J,QIN(J)
  220 FORMAT(I5,F10.0)
  222 CONTINUE
C
C***** PRINT SEPARATE HYDRAULIC INPUTS
C
      WRITE(6,223)(J,QINEV(J),QINPR (J),QIN(J),J=1,NJ)
  223 FORMAT(1H1////
     *  50H JUNCTION    EVAPORATION    PRECIPITATION      QIN/
     *  51H                (CFS)             (CFS)          (CFS)//
     * (I7,F17.1,F17.1,F10.1))
C
      WRITE(8,224)(J,QIN(J),J=1,NJ)
  224 FORMAT(I5,F10.1)
C
C***** COMPUTE NET WITHDRAWAL OR DISCHARGE AT AT EACH JUNCTION
C
      DO 228 J=1,NJ
      QIN(J) = QIN(J) + QINEV(J) - QINPR (J)
  228 CONTINUE
C
C***** LIST PREPARED INPUT DECK
C
      WRITE(6,229)
  229 FORMAT(1H1////
     *  49H ***** LISTING OF INPUT DECK PREPARED IN THIS RUN///
     *  66H JUNC.    HEAD       SURFACE      INPUT-     CHANNELS ENTERING
     *JUNC./
     *  38H                      AREA       OUTPUT/
     *  37H           (FT)      (SQ.FT)      (CFS)//)
C
      DO 232 J=1,NJ
      WRITE(6,230)J,Y(J),ASUR(J),QIN(J),(NCHAN(J,K),K=1,5)
  230 FORMAT(I5,F10.4,F14.1,F10.1,I8,4I5)
  232 CONTINUE
C
C***** PUNCH INPUT DECK FOR HYDRAULIC RUN
C
      DO 234 J=1,NJ
      WRITE(8,233)J,Y(J),ASUR(J),QIN(J),(NCHAN(J,K),K=1,5)
  233 FORMAT(I5,F10.4,F10.1,F10.1,5I5)
  234 CONTINUE
C
C***** COMPUTE TOTAL EVAP AND PRECIP FROM ENTIRE SYSTEM
C
      QEVT = 0.0
      QPRT = 0.0
      QNET = 0.0
      DO 302 J=1,NJ
      QEVT = QEVT + QINEV(J)
      QPRT = QPRT + QINPR (J)
      QNET = QNET + QIN(J)
  302 CONTINUE
```

```
      WRITE(6,322) QNET,QEVT,QPRT
  322 FORMAT(27HONET OUTFLOW FROM SYSTEM = F10.1,4H CFS/
     *        33H TOTAL EVAPORATION FROM SYSTEM = F10.1,4H CFS/
     *        33H TOTAL PRECIPITATION ON SYSTEM = F10.1,4H CFS////)
C
      WRITE(6,324)
  324 FORMAT(11H END OF RUN)
C
      CALL EXIT
      END
```

```
PREPARE INPUT DECK FOR HYDRAULIC RUN FOR SAN DIEGO BAY                    FEDERAL WATER QUALITY ADMINISTRATION
MEAN SEPTEMBER CONDITIONS                                                 DATA PREPARATION PROGRAM


MONTH =   9

EVAPORATION =     4.80 INCHES

PRECIPITATION =     0.0  INCHES




         JUNCTION   EVAPORATION   PRECIPITATION    QIN
                       (CFS)          (CFS)        (CFS)

             1           0.8             0.0        0.0
             2           0.5             0.0        0.0
             3           1.6             0.0        0.0
             4           1.8             0.0        0.0
             5           1.2             0.0        0.0
             6           0.9             0.0        0.0
             7           0.5             0.0        0.0
             8           0.6             0.0        0.0
             9           0.9             0.0        0.0
            10           0.5             0.0        0.0
            11           1.0             0.0        0.0
             •            •               •          •
             •            •               •          •
             •            •               •          •
            46           0.7             0.0        0.0
            47           0.6             0.0        0.0
            48           0.9             0.0        0.0
            49           0.8             0.0        0.0
            50           0.9             0.0        0.0
            51           0.8             0.0        0.0
            52           0.7             0.0        0.0
            53           0.6             0.0        0.0
            54           0.6             0.0        0.0
```

```
 55    0.7    0.0     0.0
 56    0.4    0.0     0.0
 57    0.5    0.0     0.0
 58    0.3    0.0     0.0
 59    0.6    0.0     0.0
 60    0.4    0.0     0.0
 61    0.4    0.0     0.0
 62    0.4    0.0     0.0
 63    0.5    0.0     0.0
 64    0.3    0.0     0.0
 65    0.8    0.0     0.0
 66    0.7    0.0     0.0
 67    0.8    0.0     0.0
 68    1.0    0.0     0.0
 69    0.8    0.0     0.0
 70    1.0    0.0     0.0
 71    0.7    0.0     0.0
 72    0.9    0.0     0.0
 73    1.0    0.0     0.0
 74    0.8    0.0     0.0
 75    1.2    0.0     0.0
 76    0.9    0.0     0.0
 77    0.9    0.0     0.0
 78    0.4    0.0     0.0
 79    1.3    0.0     0.0
 80    0.9    0.0     0.0
 81    0.5    0.0     0.0
 82    1.2    0.0     0.0
 83    0.9    0.0     0.0
 84    0.6    0.0     0.0
 85    1.2    0.0     0.0
 86    0.9    0.0     0.0
 87    0.5    0.0     0.0
 88    0.7    0.0     0.0
 89    1.1    0.0     0.0
 90    1.0    0.0     0.0
 91    1.1    0.0     0.0
 92    0.8    0.0     0.0
 93    0.8    0.0   646.0
 94    1.0    0.0     0.0
 95    0.9    0.0     0.0
 96    1.0    0.0  -646.0
 97    1.0    0.0     0.0
 98    1.0    0.0     0.0
 99    0.4    0.0     2.6
100    0.6    0.0     0.0
101    0.6    0.0     0.0
102    0.1    0.0     0.0
103    0.2    0.0     0.0
104    0.2    0.0     0.0
105    0.2    0.0     0.0
106    0.2    0.0     0.0
107    0.4    0.0     0.0
108    0.4    0.0     0.0
109    0.4    0.0     0.0
110    0.5    0.0     0.0
111    0.5    0.0     0.0
112    0.5    0.0     0.0
```

```
***** LISTING OF INPUT DECK PREPARED IN THIS RUN

JUNC.    HEAD       SURFACE      INPUT-     CHANNELS ENTERING JUNC.
                     AREA        OUTPUT
         (FT)       (SQ.FT)      (CFS)

   1    2.6020    5500000.0        0.8      1    2    0    0    0
   2    2.6020    3125000.0        0.5      2    0    0    0    0
   3    2.6020   10500000.0        1.6      1    3    0    0    0
   4    2.6020   11454545.0        1.8      3    4    0    0    0
   5    2.6362    7827273.0        1.2      4    5    6    0    0
   6    2.6578    5781818.0        0.9      5    8    9    0    0
   7    2.6489    3436363.0        0.5      6    7    0    0    0
   8    2.6620    3627273.0        0.6      7    9   10    0    0
   9    2.6754    5645455.0        0.9      8   11    0    0    0
  10    2.6842    3163636.0        0.5     10   13   14    0    0
  11    2.6934    6763636.0        1.0     11   12   13    0    0

   •       •          •              •      •    •    •    •    •
   •       •          •              •      •    •    •    •    •
   •       •          •              •      •    •    •    •    •

  93    3.0133    5427273.0      646.8    140  141    0    0    0
  94    3.0123    6790909.0        1.0    137  141  142  143    0
  95    3.0084    5972727.0        0.9    138  139  142  144    0
  96    3.0218    6572727.0     -645.0    145  147    0    0    0
  97    3.0171    6272727.0        1.0    143  145  146  148    0
  98    3.0146    6245455.0        1.0    144  146  149    0    0
  99    3.0218    2645455.0        3.0    147  150  152    0    0
 100    3.0194    4118182.0        0.6    148  150  151    0    0
 101    3.0173    3900000.0        0.6    149  151    0    0    0
 102    3.0257     545455.0        0.1    152  153    0    0    0
 103    3.0329    1309091.0        0.2    153    0    0    0    0
 104    2.8995    1281818.0        0.2    154  155  156    0    0
 105    2.9110    1390909.0        0.2    156  157    0    0    0
 106    2.9167    1390909.0        0.2    158    0    0    0    0
 107    2.9330    2727273.0        0.4    159  160    0    0    0
 108    2.9413    2563636.0        0.4    160  161  162    0    0
 109    2.9485    2836364.0        0.4    162  163  164    0    0
 110    2.9527    2945455.0        0.5    164  165    0    0    0
 111   -3.0000    3125000.0        0.5    170    0    0    0    0
 112   -3.0000    3125000.0        0.5    170    0    0    0    0

NET OUTFLOW FROM SYSTEM =          80.3 CFS
TOTAL EVAPORATION FROM SYSTEM =         77.7 CFS
TOTAL PRECIPITATION ON SYSTEM =          0.0 CFS


END OF RUN
```

* U. S. GOVERNMENT PRINTING OFFICE : 1970 O - 404-617